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SOME PROBLEMS IN THE ASTRONOMY OF PRECISION.

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FOR POPULAR ASTRONOMY.

At the request of its editor I take pleasure in contributing to the pages of POPULAR ASTRONOMY a short account of some investigations made at the Washburn Observatory which are set forth in detail in Vol. IX of its Publications, recently issued from the press. The purpose of the work was a determination of the value of the constant of aberration and, simultaneously, an investigation of the amount of the atmospheric refraction. Strangely enough no thorough investigation of the refraction, save the present one, has ever been made in America and although there is no theoretical reason for supposing the refraction to be sensibly different in corresponding latitudes of the old and new worlds an investigation of the matter was to be desired, and since the best tables of the refraction present sensible discordances among themselves and from the results obtained at Observatories from Pulkowa to the Cape of Good Hope the problem of improving the tables seemed worthy of attention. A special interest attaches to the aberration work since the recently discovered variations of latitude throw considerable doubt upon the earlier determinations of this important constant and the method of research which I have adopted possesses the important advantage of being independent of the direction of the vertical and therefore absolutely unaffected by these changes.

The method of research is in substance an application of the ingenious device suggested and first employed by M. Loewy, Director of the Paris Observatory, viz. the placing of two mirrors before the objective of a telescope and from them reflecting simultaneously into the field of view two very different parts of the heavens. The angular distance between stars thus seen may be determined with a micrometer when the angle between the reflecting surfaces is known. The mode of procedure suggested by M. Loewy is a purely differential one, *i. e.*, depending upon the difference of length of two arcs measured upon the same night, and I have radically departed from his methods in seeking to extend the principle to the measurement of the absolute lengths of

the arcs and have thus been led, partly by theoretical considerations partly by experience, to profoundly modify both the apparatus and the methods of research. Without going into details with regard to these modifications suffice it to say that they accomplish the purpose for which they were intended and render possible the measurement of long arcs, 120°, with micrometric precision and thus furnish an excellent method for dealing not only with the problems originally contemplated, but also with a considerable number of subordinate ones among which an increase in the precision of the right ascensions of the fundamental stars holds a conspicuous place.

The instrument with which the observations were made is the six-inch Clark equatorial telescope used by Mr. Burnham in his earlier double-star work, which has been remounted to adapt it to the present research and has been provided with a system of three reflecting surfaces placed in front of the objective. A large part of the expense of these alterations was met by an appropriation from the National Academy of Sciences, made in aid of the work.

The theory of the apparatus shows that the mirrors should occupy definite positions with respect to the telescope and that any deviation from these positions such as might be caused by looseness of the mirrors or bending of the apparatus under its own weight will introduce a small amount of error into the observations. These errors of adjustment although of trifling amount were carefully determined from time to time and their effect duly taken into account. From a discussion of several hundred observations it appears that the apparatus is capable of furnishing a very considerable degree of precision in the measured distances, the probable error of a single observation made under normal circumstances being less than a millionth part of the quantity measured.

The distances thus measured constitute the data of the problem and by a laborious numerical computation there is to be derived from the annual variation in these distances a value of the aberration while a comparison of the measured distances with those computed from the known right ascensions and declinations of the stars furnishes the refraction. The latter part of the program was supplemented by a series of independent measurements of the circumference of the heavens from which the refraction may be determined through the condition that the measured circumference plus the refraction must equal 360°. In addition to these main lines of research it became necessary to conduct a se-

ries of subsidiary investigations whose results may be briefly noted as follows:

A. The indications of a whirled thermometer swung at night, in the open air, are affected with errors which required the substitution of a specially devised ventilating apparatus for the exposure of the thermometers upon whose indications the computed refractions depend.

B. The presence of aqueous vapor in the atmosphere exercises a sensible influence upon the amount of the refraction, and this influence is correctly represented in magnitude and sign by a theoretical formula involving laboratory determinations of the refractive indices and co-efficients of expansion of air and aqueous vapor.

C. The dispersion of light by the atmosphere produces a sensible effect upon the refractions suffered by stars of different colors. Following the color indications of the Potsdam spectroscopic survey the refraction suffered by a pair of average ruddy-yellow stars is found from observation to be 0″.26 less than that of a pair of white stars. This result is in substantial agreement with the dispersion formula derived from laboratory experiments by Kayser and Runge.

D. The refractive index, for the D line of the spectrum, of dry air under standard temperature, pressure and gravity is found from the present series of observations to be 1.0002921 ± 7.10^{-8}. The recent laboratory determinations of this constant accessible to me are included between the limits, 1.0002911 and 1.0002927 and their mean is 1.0002920.

D. The coefficient of expansion of air under constant pressure, per degree centigrade, was determined from observations separated by intervals of only a few days or weeks in order to avoid the effect of any seasonal variation in the refraction not adequately represented by theory. The resulting value, 0.003674, does not sensibly differ from Regnault's laboratory determination.

F. When the coefficient of expansion of air above determined is introduced into the refraction tables, they represent the seasonal variation of the refraction with a high degree of precision. The observations, however, indicate that the tabular refraction requires a very small negative correction in the first half of the year and a corresponding positive correction in the second half.

G. The right ascensions of the *Nautical Almanac* and of the *Connaissance des Temps* for the year 1883, are affected with periodic errors which are functions of the right ascension. These

errors, if not altogether absent, appear in much smaller measure in the *American Ephemeris* and the *Berliner Jahrbuch.*

H. Meridian determinations of right ascension in general make the right ascensions of the fainter stars too great. In the places adopted for the present investigation this effect amounts to $0^s.009$ per magnitude.

Of these results C and D depend in part upon the adopted coordinates of the stars, while A, B, E and F are derived from differences of observed quantities and are therefore free from all assumption with reference to the star places. The close agreement of C and D with the results of laboratory determinations made under entirely different circumstances may be regarded as some indication of the substantial accuracy both of the adopted star places and of the observations. A further proof is found in the following accordant values of the correction to the average refraction, $R = 195''$, furnished by the Pulkowa Tables for an average pair of stars separated by an arc of approximately $120°$:

From the measured circumference of the heavens $\Delta R = +0''.39$
From the assumed coordinates of the stars $\Delta R = +0\ .38$

A correction for the difference in the force of gravity at Pulkowa and Madison is included in this comparison of the tables with observation and if this term had been omitted the observed correction to the tables would have been less than $0''.1$. This may be regarded as a confirmation of the substantial accuracy of the Pulkowa mean refractions for the latitude of Madison, but in view of the results above designated, B, C and E, it appears that no constant correction to the tables can be made to represent the observations within limits fixed by their own measure of precision.

When the results above set forth are duly incorporated with the data directly observed, a solution of the corresponding equations furnishes as a definitive result

$$\text{Constant of Aberration} = 20''.443 \pm 0''.010$$

which differs from the commonly accepted value (Struve) by much less than its own probable error. The value of this constant adopted at a recent conference of the superintendents of the several national ephemerides is $20''.47$.

RESEARCHES ON THE EVOLUTION OF STELLAR SYSTEMS.

S. W. BURNHAM.

For Popular Astronomy.

Dr. See's great work on the evolution of the stellar systems has recently been issued from the Nichols press, publishers of Gould's Astronomical Journal, in a handsomely printed quarto of 250 pages, and presents the most complete and elaborate work ever issued upon theoretical subjects relating to double stars. It is safe to say that it includes substantially all that is certainly known relating to binary systems where the observations are sufficient to give data for the determination of the elements of the orbit. The number of these systems is much smaller than many have heretofore supposed who based their opinion upon the whole number of pairs whose orbits have been computed. Those who have given no special attention to this important department of sidereal astronomy, other than becoming familiar with the results of investigations published in the leading astronomical journals, have supposed, and not without justification, that when an eminent mathematician, well known in astronomical work, made an elaborate investigation of the elements of a binary system, based upon all the available observations, discussed with all the refinements of modern analysis, and with the values given to remote decimal places, the orbit was necessarily known to within small limits of error, and that the only thing left for future observers and computers to do was to furnish the material and make relatively insignificant corrections for the final orbit. It has been inferred that because orbits have been computed by the best mathematical authorities from time to time in this way of not less than eighty different binary systems, that therefore the motions, periods and elements of at least that number of double stars were well, or closely approximately understood. I have pointed out heretofore how ill-founded any such inference appears when the data is examined upon which results are based. It is apparent to the most unmathematical reader who will take pains to look into the material furnished by the observations, that in the majority of these systems the conclusions reached were without foundation; that there was nothing upon which to base even a guess, to say nothing of results, which purport upon their face at least, to give definitive results with the highest degree of accuracy and precision; and that these investigations were not only of no benefit to the science of as-

tronomy, but were a positive injury in leading many to believe from these learned discussions that the history and movements of these systems were understood, and the given elements were at least substantially correct. It is a matter of no consequence that the time spent in the last fifty years in the computation of not less than 60 orbits of systems, about which in the nature of things the astronomers of this century can have no definite knowledge whatever, was wasted; but the erroneous results are scattered through the standard astronomical literature, and have misled many, as they will continue to do, with reference to the extent of our knowledge of the binary systems.

In a recent article (POPULAR ASTRONOMY, Oct., 1896) I have endeavored to present in a brief way a summary and classification of the material in the way of double stars, giving as nearly as it can be done at this time, the number of known and probable binary systems, and the number of pairs from which we may expect additions to the physical systems in the future. From this it appears after a careful examination of all the stellar systems within 120° of the north pole, that while we have only 36 binaries whose orbits can be said to be well determined, there are about 230 other pairs probably binary, and a further number of 1600 pairs which from the closeness of the components, their common proper motion, and for other reasons, may be presumed to belong to the class of physical pairs, although in many instances it may require hundreds or thousands of years to make this absolutely certain from micrometrical observations.

Chapter I of Dr. See's work is devoted to the history of the development of double-star astronomy, and the mathematical theories of the motions of binary stars. He gives a historical sketch of this subject from Herschel to the present time; and an exposition of the different methods of determining orbits, including the methods of Kowalsky, Klinkerfues, Glasenapp and others by graphical and analytical processses. Other sections of this chapter are devoted to Laplace's demonstration of the law of gravitation in the planetary systems; the theoretical possibility of determining the distances of star clusters and the Milky Way; formulæ for the improvement of elements; a general method for the solution of Kepler's equation by mechanical means, and other investigations involving the higher mathematics. In this chapter the author has dwelt at some length upon the evidence, from a mathematical point of view, of the existence of the law of attraction in the stellar systems, and has given a rigorous method for testing the universability of this law. Treated in this

way, the subject is not without interest to those who are able to follow the writer in a field that is purely mathematical, but the question seems hardly debatable, or one requiring proof, if the Newtonian law is admitted to be correct anywhere. One might as well expect that a visitor from the Earth to the system of Sirius, who had not forgotten the value of π, would find it necessary to re-determine the ratio of the diameter of a circle to the circumference, as to expect to find there any change or modifications in the great law of attraction.

Chapter II contains the results of the investigation of the orbits of forty binary stars. The author does not say directly that these are all the known systems for which there is the requisite data for definitive orbits, although that is implied. Certain it is that nothing has been omitted which under this limitation should have been given. In fact, one or two of the stars could have been rejected for the uncertainty arising from the early positions in the last century, thus reducing the observed arc below the required limits. With three exceptions, γ Centauri, α Centauri and γ Coronæ Australis, these systems are measurable at all observatories in the northern hemisphere. The observations are carefully collected and tabulated, and each system is represented by a full page diagram giving the apparent orbit, and the several positions relied upon for the determination of the elements. The corrections to the observed positions to make them conform to the orbit thus found are also given, as well as the details of the apparent ellipse from which the orbit can at once be accurately put on paper. The importance of giving a diagram, drawn to scale, showing the measured positions and the deduced orbit, cannot be overrated. It enables the reader to judge at once of the real value of the result; how well the measures as a whole are represented; and whether or not the apparent orbit is the only one which will satisfactorily represent the observations. If this test of the value of an orbit had been given long ago by computers in connection with their work, the uncertainty in many instances would have been so obvious even to the author that the result would never have been published at all. Such a defect cannot be seen, even by one experienced in such matters, in tabulated results, however elaborately presented.

Chapter III is devoted to a general discussion of the results of the researches of these orbits, and general considerations respecting stellar systems. The elements of the forty orbits investigated are presented in tabular form, together with the data for laying down the apparent orbits, proper motions, magnitudes, light-

ratio, etc. The author then discusses the relative velocity of the companion in the line of sight, and the possible relation of orbit-planes of binary systems to the plane of Milky Way. The high eccentricities found in the binary systems is shown to be a fundamental law of nature. The mean eccentricity of the forty orbits is 0.482, while the corresponding mean of all the planets of the solar system is only 0.06. Many of the satellites appear to move in orbits sensibly circular, and in the others the eccentricity is only half that of the planets.

The book is remarkably free from typographical and other errors, and the occasional slips are of comparatively small importance, as for instance two of the orbits of ξ Ursæ Majoris, credited to Knott and Pritchard, were really made by Hind and Plummer respectively; and Wijkander's orbit of η Coronæ, which is given twice, and one of them ascribed to Dunér. Dr. See's work must necessarily be a standard book of reference for many years to come. Additions to a catalogue of this kind will come very slowly. There can be very few from the older double-star catalogues in the next fifty years, and practically all the binary systems for which there will be data for definitive or approximately accurate orbits within the next quarter of a century will come from recent discoveries of very close pairs where the motion is so rapid that measures during a comparatively short time will furnish the required data. During this interval there will be little need for the services of the computer; the practical observer with the micrometer, working on a wisely selected list of double stars, cannot do too much.

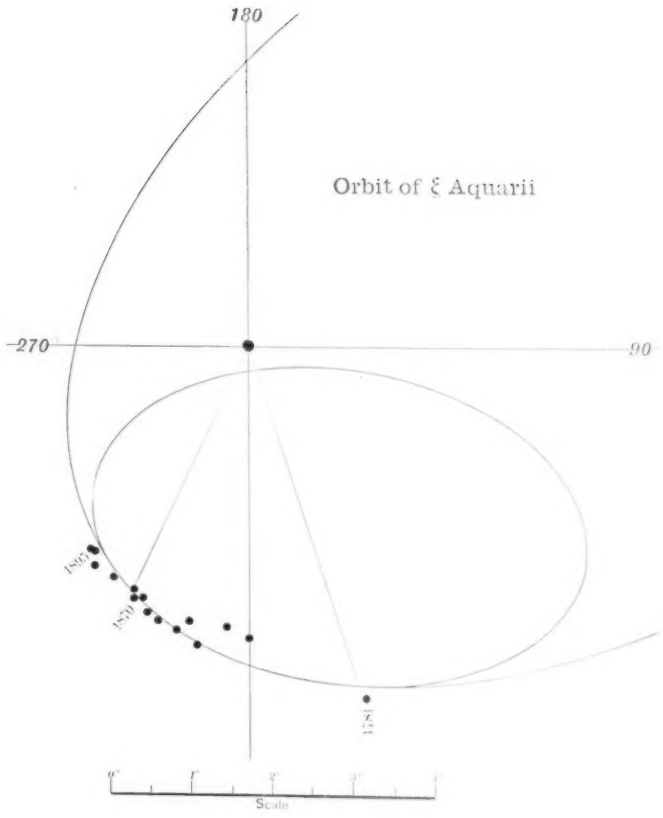
THE ORBIT OF ξ AQUARII. Σ 2909.

S. W. BURNHAM.

For Popular Astronomy.

This double star was observed by the first Herschel in 1779, but it had been previously recognized as double by Mayer in 1777. Herschel measured the angle and distance several times, and gave the mean of two years measures in his first catalogue. The magnitudes of the components are almost exactly equal, 4.0 and 4.1 according to Struve; and the position angle is occasionally reversed by some observers. These stars have a common proper motion of 0″.155 in the direction of 74°. Herschel in 1804 first recognized the angular change that had already taken place, and this was confirmed by Herschel II in 1821 from his own measures. Speaking of the proper motion according to

PLATE XLV.



Piazzi, and the apparent absence of relative change from this cause, Herschel said, "this circumstance alone amounts to a proof of their mutual connection, which their equal size corroborates, and renders it exceedingly probable that they form a binary system."

The retrograde motion of the companion has gone on steadily, accompanied with a small diminution in the distance, the total angular movement from 1781 to 1895 being about 56°. Doberck, using the measures to 1870, has computed a provisional orbit (*Trans. R. I. Acad.* XXV), and found a period of 1578.33 years; but as the total arc described down to that date was only 43°, it is obvious that no trustworthy result could be reached.

It is an easy object at all times, within the reach of the smallest equatorials, and the measures are very numerous. On the accompanying diagram are given fifteen positions made at intervals between 1781 and 1895 by the following observers:

1871	H	1	1858-76	⊿	5
1825, 1832	Σ	2	1883, 1888	Hl	2
1839, 1846	Da	2	1893	Maw	1
1853	Ma	1	1895	See, Com.	1

The large ellipse is the orbit found by Doberck. This is based upon the arc included between the radial lines from the principal star to the positions of 1781 and 1870. The small ellipse is merely to show that this short arc and the computed positions deduced from that orbit, can be perfectly represented by an almost infinite variety of curves, and that therefore we know absolutely nothing at this time of the form of the apparent orbit, or the elements of the real orbit. An ellipse which will enclose the principal star, and give an eccentricity of 0.9, the highest eccentricity of any known double star system, will require a period of about 350 years, which may be considered as the minimum periodic time. The probabilities are that it will require the measures of at least 500 years to furnish data for a definite solution of the problem.

GENERAL PROBLEMS OF CELESTIAL MECHANICS*

For a long time the zodiacal light was regarded as an inexplicable phenomenon and this view is held by many even today. But to me it seems that artificial difficulties which in reality do not exist, have here been lugged in and I contend that this phenomenon can in all its essentials be explained by the assumption

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that the space of the solar system from the central body to regions beyond the orbit of the Earth is filled with a layer of cosmic dust which, reflecting the Sun's light produces the soft glow of the zodiacal light.[3]

If we accept this explanation we see in it a second proof of the presence in extended regions of the solar system, of a great mass of small particles. This conclusion is of no small import since in the first analysis the appearance of a star shower warrants an inference only in regard to those localities which the Earth touches during her annual journey around the Sun.

The effect of such sparsely strewn matter upon the movements of the planets will readily be seen to resemble that ascribed above to the luminiferous aether, for in this as in the former instance the planets experience a resistance or checking in their motions.[4] We see therefore in the cosmic dust a second securely established cause striving to bring about the destruction of the planetary system and ultimately making probable the combination of all the planetary masses into a single one. As a matter of course, we are not at present able to regard this prospect in the light of a future certainty, inasmuch as it is always conceivable and indeed possible, that before this final condition shall be reached the entire supply of cosmic dust shall have been absorbed by union with the planets and thus an empty space created which will then make possible free and unhindered motion according to Newton's law, but of course, then, under essentially modified conditions.

[3] Two chief objections have been raised against this explanation. The first is that the spectrum of the zodiacal light should show a bright line, the line of the Aurora Borealis. Recent investigations have shown that it can be proved with almost absolute certainty that reflected solar rays alone are present in zodiacal light. The second objection rests upon the computation of the distribution of brightness which, according to the view expressed in the text must characterize zodiacal light. It is specially to be noted that the explanation of the so-called counter-glow cannot be well derived from such computations. In the meantime, the error has been made of taking Lambert's photometric law as a basis. That this law has in no wise been proved, either theoretically or practically, the writer has in several places attempted to show. It will be especially far from the truth in cases where we have to do with light reflected by small bodies with very rough surfaces. If now, we set aside Lambert's law, the above mentioned computation loses, of course, its entire value. It can also be easily shown, moreover, that we may then represent the distribution of brightness in the zodiacal light very well. Unfortunately, there are at hand almost no observations at all on the relative brightness of the individual parts of the zodiacal light; and we cannot at present therefore, discuss the subject as much in detail as might be desirable I hope, moreover, to return shortly in detail to this point in another place.

[4] I have shown in the treatise cited in remark [2] that assuming the motion of meteors near the Sun to be in all possible directions, one is led to the same law of resistance which the motion of Encke's comet requires. It seems to me therefore highly probable that the much discussed anomaly in this comet's motion is caused by collision with the cosmic dust which in regions near the Sun at least, is collected in considerable quantities.

But despite all this, we may yet seek consolation and find hope in the circumstance that on the whole, the present condition of the planetary system which favors and fosters the prosperity of organic matter upon the Earth and perhaps upon other planets as well, will suffer only inconsiderable changes and that the planetary system is, so to speak, in a *stable* condition.

And yet even this hope is delusive and must be dismissed as unjustifiable when tested in the light of the facts.

The present condition of our planetary system may from two sources, suffer such important physical changes that stability in the sense, in which human beings must clearly be vitally concerned, is wholly out of the question. In the first place, the mutual attraction of the planets, alone, to say nothing whatever of the above mentioned frictions and collisions, could produce such a change in the configuration of the system, that through it, the physical conditions for the existence of the individual planets might become wholly and widely different. For example, if it were possible that the Earth should some day become displaced to a distance from the Sun equal to the distance of Jupiter at present, or equal to Mercury's distance, the existence of organic life on its surface would probably then be forever at an end. For in the first case, our Earth would be stiffened with the gruesome cold and in the second, stifled in smothering heat. But even if this were not possible, if the geometric relations in the solar system should remain unchanged forever, we are still forced to question whether the physical conditions of the individual bodies are not engaged in a gradually advancing process of development which must necessarily lead to an end not calculated to flatter the egotistical ideas of humanity. Of what use would it be to us for the Earth to circle about the Sun in precisely the same path for all eternity, if with the lapse of time it should lose its light and heat energy? I will not trace the details of the picture farther, for the consequences of such a condition of things are self evident. Let us however consider what information on both sides of the question of the stability of planetary relationships, scientific research can furnish.

The first question is purely mathematical and may be stated thus: are the forms of the orbits described by the planets variable by reason of the mutual effects of the planets, only within certain narrow limits? Mathematical investigation is at present unable to answer this, although it has for years been engaged upon it and has recently been specially energetic in its attacks upon this extremely difficult problem which to all appearances,

still transcends the power of the analytic instruments now at disposal. For example, we cannot say whether our Earth will always continue to move about the Sun in those regions which it traverses to-day, or whether in the process of time it will depart far from these regions. We must point out this condition of things with special emphasis because not alone in popular treatises relating to the stability of the planetary system is this matter regarded as a thoroughly well established and mathematically demonstrated conclusion, but rather because in other departments of science extended use of the same assumption is made. Certain writers support themselves in this maintenance upon the celebrated investigations of Laplace, according to which the mutual effects of the planets may only produce such changes of their orbits as are included within somewhat narrow limits. This result cannot now be regarded as proved according to the modern status of science. It is in point of fact quite easy to discover the logical circle by which it was reached. On the other hand it would be equally false to affirm the opposite view as correct or even as probable. It is therefore necessary for us to admit that the question is at present wholly an open one.[5]

To the second question on the contrary, we can give a definite answer on the basis of physical facts and knowledge. Let us examine this matter by beginning our consideration with a generally conceded position.

Scientists and philosophers of all times have refused to be satisfied with simply accepting the present condition of the universe as a given fact, and there has been a never ceasing attempt to regard it as a stage in a long process of development. Science must needs be content with pursuing this process through a very few stages, for its beginning and end will ever remain veiled in darkness because human understanding will never be able to comprehend the ideas of infinity of time and space. A train of thought apparently free from this limitation and on this account alone, in the highest degree remarkable, has been furnished by the mechanical theory of heat. A single law generally known as the "Prin-

[5] Wundt's remarks (System der Philosophie S. 483ff) concerning Laplace's proof of stability seem to rest upon a misconception. The question involved is not a "principle of stability," for such is wholly unknown to astronomers, but it is purely a mathematical question, viz: whether certain differential equations have purely periodic solutions if the constant of integration possess values corresponding to observation. In his consideration of planetary motion, Laplace has necessarily disregarded all such effects as friction, resistance, etc. etc., otherwise his differential equations had not defined the problem at all. To detect an inconsistency in the divergence of the results of this purely mathematical question and the conclusions of Laplace's Nebular Hypothesis is therefore wholly out of place.

ciple of the Conservation of Force" dominates the entire realm of modern exact science. According to this law, the assumption of the invariability of the quantity of matter present in the universe and of the invariability of the supply of force or quantity of energy extant in the universe are to be placed side by side as of equal importance. Forms of motion of matter only *appear* to vanish, in their stead others must arise, determinable according to fixed relations. Transformations of individual forms of energy into one another are continually occurring.

The motion of a falling stone when arested, is changed into a motion of the finest particles of the body and we call this form of energy, *heat*. Conversely the locomotive transforms before our eyes daily, heat into the motion of mass, and similarly magnetic and electrical forces are transformed into one another. The sources which are thus offered to man enabling him to compel nature's forces to do his bidding, are inexhaustible and technical science in its giant strides has not hesitated to draw from these springs. What we ourselves are thus able to do continually and with ever increasing success for the accomplishment of our purposes, nature effects of herself, on a far grander scale and according to fixed laws.

Star dust in the condition of small, non-luminous particles, penetrating our atmosphere loses here by friction almost its entire velocity; but this velocity is not irrecoverably lost from the household of nature. It is in fact merely transformed into heat which raises the temperature of the dust to glowing and often dissipates it into vapor. The temperature of the air is also raised and just here occurs a partial re-transformation into actual mass motion through the expansion of the heated air, the production of atmospheric currents, etc.

If now, it were immediately and easily possible to transpose the various forms of energy in any and all directions indefinitely we should obviously have as a rule, periodic processes to consider. But applied to the physical condition of the system of the universe as a whole, the matter would stand about thus: howsoever the present condition of the individual bodies may be constituted, so soon as a part of the mass motion is apparently lost through resistances and friction, it must re-appear in a corresponding quantity of heat.

Let us now assume that the previously described final conditions were actually brought about, that therefore all the bodies of the planetary system have united into one mass of high temperature, of course. The motion of all the planets is thus for the time being

transformed into heat. The process is however, by no means terminated with this. We have absolutely no reason for denying that out of this combined mass, energy of motion (kinetic energy) may again be produced and that therefore a new planetary system might arise out of the ruins. We may imagine this process many times repeated without coming into contradiction with the laws of nature, and we have thus an entire chain of developments in which the end of each link is the beginning of a new one. Can this process though, be renewed in periodic rhythm throughout all eternity? Were this the fact we could still in a certain sense, speak of the eternal duration of our system and we would here have before us the same spectacle, though of course, on a much larger scale as that which we see unfolding in the organic world.

Just as the individual after a short period, passes away, whereas the race in its entirety is preserved, sometimes in continuous succession, sometimes in periods separated in time, by the dying generation leaving behind the seed of the next succeeding, so would each planetary system contain at the instant of its own collapse the basis for its re-suscitation in a changed form.

In the universe as a whole however, we are informed by modern physics that a similar process could not occur, since the assumption above that the transformation of various forms of energy into one another may be performed with equal facility, does not hold. In general, transformations of kinetic energy into heat are in excess of the converse process. The farther therefore, the universe advances in its development, the more energy will have been transformed into heat, and since this condition is continued incessantly in the same direction, the future of the universe would differ from that sketched above in one essential respect.

Periods of resurrection of new systems and decay of old, might perhaps follow each other in long succession, but the acts of re-juvenation must gradually and generally diminish in intensity and the entire universe strive incessantly toward a final condition in which all kinetic energy will have been transformed into heat and all space will have been reduced to a uniformly frigid temperature with no motion possible. This prospect is to say the least, not very consoling, nor is it specially edifying to human thought to contemplate a picture which portrays the eternal stagnation of the mechanism of the universe. The consistency of the conclusions which lead to the sketching of this picture, is not to be doubted even in detail. But the notions of an infinite space and of an infinite time are for us inconceivable and since it cannot be doubted that the result just stated is based on both these

ideas, it cannot carry absolute conviction to our minds despite all this. We will furthermore, scarcely be able to get beyond the difficulty that all natural laws represent merely abstractions from experience; and that we are therefore, scarcely warranted in extending what has been thought and experienced in such a narrow circle by humanity to intervals of time which we must designate not as very long but as absolutely infinite.[6]

Even though one should be inclined to contest the correctness of these reflections, though he should be disposed to regard even the dissolution of the planetary system as following from poorly sustained hypotheses, yet the conviction that the present condition of the heavenly bodies and especially of our Earth is ephemeral, can in no wise, be shaken. There can indeed be no doubt that all the heavenly bodies must gradually yield up to space their store of internal heat through radiation. The same destiny which, in all probability, has already overtaken our constant companion, the Moon, awaits undoubtedly the Earth also, and finally the Sun itself. Light and heat will disappear and with them everything which makes life possible upon our globe.

And why should there occur here an exception nowhere else to be observed, and which we are by no means willing to grant? Matter is every where subject to continual change; and the smallest living being, as well as self-luminous suns are all moving between a beginning and an end. Everything in nature has a time of bloom, of greatest possible development of its forces and finally of old age and of dissolution. And toward this dissolution every thing earthly is moving without cessation, wholly unmindful of the feelings of the thinking being.[7]

(TO BE CONTINUED.)

[6] To avoid going farther into details I have above used the expression that various forms of energy may not always be transformed into one another with equal facility. This expression if taken in the sense in which it is used in the theory of heat, is of course incorrect. But we are here concerned with transformations which as Clausius says, "may be carried on in a certain positive sense, of themselves, i. e. without compensation; that they may occur in an opposite or negative direction only in such way as to be compensated by transformations simultaneously occurring in a positive sense." Clausius has them obtained as a final result of his investigations, the two propositions (1) The energy of the universe is constant; (2) The entropy of the universe is ever striving toward a maximum.

[7] Concerning those sudden catastrophies bearing in themselves the stamp of the accidental, nothing was said above where we were only touching upon what could be said in advance with greater or less certainty. But that such catastrophies of worlds are by no means seldom, is proved by the socalled *new stars* Phenomena of this sort heretofore observed, together with the application of the methods of spectral analysis, show very distinct discrepancies among each other. We shall accordingly hope to find an explanation of the appearance of new stars only in hypotheses which, without constraint, admit far-reaching modifications suited to each special case. The assumption that the blazing out of a new star arises from a collision of two celestial bodies, is of such a character. But it must

ON THE ORBIT OF SIRIUS.

NEWTON M. MANN.

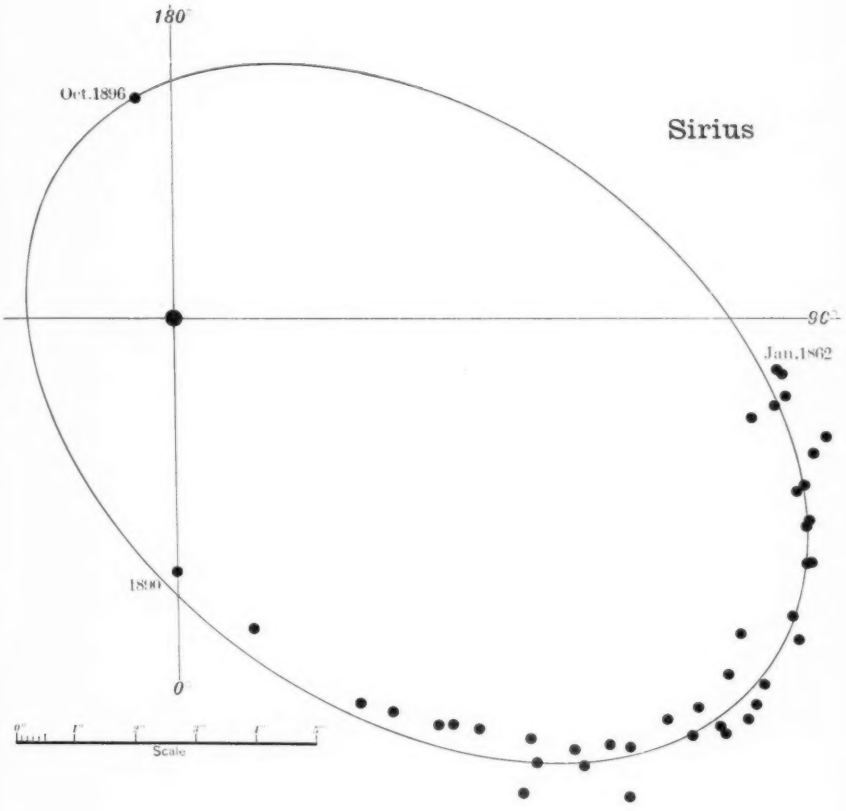
FOR POPULAR ASTRONOMY.

That the orbit of Sirius presents problems not easy of solution, they who have given much attention to it do not need to be told. The law of parsimony leads to the greatest effort to reach a satisfactory result which will involve only the two visible objects. With others who have worked to that end, I am satisfied at last that it cannot be reached. Such result as I have been able to arrive at after a good deal of labor is now submitted, not as a definite conclusion, but as an approximation to what may be called the mean orbit. I have before me, awaiting cremation, some twenty other results differing slightly from this and from one another, some of which, reached by a more determined effort to obliterate the signs of perturbation, show what, at first sight, looks like a better comparison with the observations; but a closer scrutiny led me to reject them, and to fall back upon what is here presented, which frankly admits a perturbing influence in the system.

Out of the mass of observations I have selected and charted upon the accompanying diagram 41 which may be taken as fairly representative of the whole. These cover substantially the whole period of visibility from the date of discovery down. Toward the end of the period the observations get few and far between on account of the increasing difficulty of the object, which is the greater pity as it is there that the calculated orbit is

be maintained in all the breadth of generality of which it is capable. Thus it would be unwarranted to admit of the possible existence of only such central collisions as would produce a lasting union of the two masses or to deny the existence of any but cooled suns, whose masses are relatively dense and almost spherically arranged. As to the latter point we know, or at any rate, we may assume as exceedingly probable, that numerous aggregations of a nebulous or pulverulent character often quite extensive and of most varied forms, float about through the universe. It is indeed very probable that in particular cases, denser bodies in the universe may become transformed into such extended formations which are often filled with matter in a state of extremely high subdivision. A body on passing through such aggregations and as would usually occur, with a relative velocity very high in comparison with the portions of these aggregations situated next to the moving body, would be highly heated and might then become much brighter, since under circumstances, only a small rise in temperature even though only superficial, would be required to accomplish such a result. This would give rise to the separation of gaseous particles which, retarded by the surrounding cloud of matter, would apparently be thrown off the body with high relative velocity, just as the luminous trains of the brighter meteors are rapidly left behind. We might also assume without transgressing the bounds of the permissible, that in those parts of the cloud through which the passage has occurred, deep-seated changes, such as very great elevation of temperature, have been effected.

PLATE XLVI.



most out of accord with the measures. A glance at the diagram shows that the ellipse follows the general course of the observed positions very well down to 1883, or from 85° to about 40°. From this point the observed positions are all but one inside the line. If all the observations were charted the disproportion would be yet greater. The discrepancy is glaring, and is the first thing to strike the eye. To be sure the divergency is not greater than that of many of the preceding observations, but the fact is not to be gotten over that it is altogether one-sided.

But what is thus noted is only one part of the trouble. The eye marks the discrepancy of distance; it does not readily take in discrepancy of angular position, which is an even more important consideration, for it is especially on the observed angles that we depend in constructing an orbit. For the comparison of computed with observed angles a tabular statement is required, and this ought to include all available observations; but, not to extend unduly the limits of this paper, I restrict myself to the 41 graphically represented, and one other, not represented because it is without measure of distance, but which is added in this comparison of angles for more perfect fairness. The arrangement is in the order of the angles, and not always of the dates, to facilitate identification on the diagram. The reader need only revolve a rule about the point of intersection of the right lines, to come upon them one by one, being careful to omit the third in the list, which is unnumbered to indicate that it is not charted. The angles here and in all this work are for the equinox of 1900:

	Observer.	Date.	Position-Angle.	Error.
			°	°
1.	Clark	1862.08	± 85.22	± 0.25
2.	Bond	.19	84.82	+ .14
—	Rutherford	3.10	81.42	− .67
3.	O. Struve	.21	82.72	+ .93
4.	Dawes	.23	———	
5.	Lassell	4.21	80.31	+ .66
6.	O. Struve	.22	79 71	+ .09
7.	Forster	5.22	78.14	+ .82
8.	Bruhns	6.20	———	
9.	Washington Obs.	.25	74.50	− .53
10.	O. Struve	7.22	72.30	− .64
11.	Engelmann	8.26	71.79	+ 1.00
12.	Vogel	9.15	———	
13.	Dunér	.20	68.88	.00
14.	"	71.22	64.27	− .62
15.	Washington Obs.	2.24	62.86	− .08
16.	Dunér	3.22	60.96	− .04
17.	Washington Obs.	4.14	58.15	− 1.05
18.	Dunér	5.19	57.25	− .10
19.	Washington Obs.	.23	56.35	− .72
20.	" "	6.10	55.14	− .22
21.	Burnham	7.93	53.33	+ 1.67

	Observer.	Date.	Position-Angle.	Error.
			°	°
22.	Cincinnati Obs.	.10	53.23	− .12
23.	Washington Obs.	.17	52.93	− .28
24.	" "	8.10	51.23	− .07
25.	Burnham	9.10	50.82	+ 1.65
26.	Cincinnati Obs.	.75	46.66	− 1.08
27.	Washington Obs.	81.26	45 41	+ 1.18
28.	Holden	.12	43.41	− 1.16
29.	Washington Obs.	2.23	42.60	+ .74
30.	" "	.18	42.30	+ .31
31.	Burnham	3.10	40.20	+ .69
32.	Young	.10	39.10	− .41
33.	Burnham	4.19	36.49	+ .18
34.	Hough	.05	36.09	− .64
35.	Paris Observatory	5.11	34.19	+ .79
36.	Hough	.20	32.79	− .31
37.	Washington Obs.	6.22	28.78	− .60
38.	Young	7.14	25.28	− .20
39.	Burnham	8.97	13.97	− 1.33
40.	"	90.27	359.77	− 5.59
41.	Aitken & Schaeberle	6.82	189.02	.00

This column of "errors" is to be considered in connection with the discrepancy of distance shown in the diagram. But first as to the basis of this calculation, its metes and bounds. The final datum is the observation made by Professors Aitken and Schaeberle at Mount Hamilton in the course of five nights in the latter part of October last,—position angle, 189°; distance, 3″.72. In the absence of other measures these figures are taken without modification. The point of beginning is less easy to fix upon. From the measures of the first year or two, the best date for 84° would appear to be 1862.475; to help the comparison with later observations I have put it, 1862.450. It will be noticed that down to 1865 there is a predominence of plus errors, while from that date on to 1882 the minus sign has it, though only by very moderate quantities. In 1882 the error reverts to the plus side, where it mostly continues until 1886, when it again becomes minus, and more decidedly. These are the troublesome features of this reckoning which I have sought by every expedient I could muster to get rid of. The error charged to Mr. Burnham's last, seems to practically disregard that observation. But it came to a choice between doing great violence to this one observation, and doing considerable violence to his and about a dozen other observations made between 1882 and 1886. That observation is the mean of three, which while wonderfully accordant in the measure of distance, have the following angles: 359°.6; 361°.6; 356°.8; (to each of which should be added here .06 for precession); the two last differing nearly as much as the second differs from the position the orbit which I am presenting assigns for the date of that observation.

The next disagreeable feature in the above comparison most salient is the long stretch of small minus errors between 77° and 44°. It may seem that this might be easily rectified; but how? Surely only by increasing the time allotted between the two points without changing the date assigned to 44°, or, by holding fast the date for 77° and diminishing the intervening time. The first of these procedures inevitably increases the plus errors preceding 77°, already swollen beyond reasonable limits; the second has the same effect upon the errors between 44° and 30°. There is the same difficulty about doing anything for the minus errors of the measures made subsequently to 1886. They can be helped only by extending the orbit between 360° and 189° to include more time and space; but this, if we hold fast the date for 189°, results inevitably in aggravating the preceding plus errors beyond all that can be tolerated. I ought to say that this succession of plus errors is not adequately brought out in the foregoing comparison. I have before me the record of 17 observations made between 1881.12 and 1886.22, of which in the comparison only three show minus errors.

Taking up the errors of distance in connection with the errors of angle, we find that what would rectify one set would exaggerate the other. Thus, to shorten the distance from about 40°, and run the curve where one might think from the diagram it should go, would swell the plus errors all along there beyond what could possibly be admitted. Besides, such a deviation would make it impossible to include between the radius of 40° and that of 189° the requisite area to correspond with the time. Thus it will be seen that the obstacles to any particular improvement of what is here presented are great; to me they seem insuperable.

These systematic errors, as far as then developed, were pointed out by Mr. Colbert in 1880, with some suggestions as to how the perturbation occurs. Deflection from the proper plane of the orbit, first to one side and then to the other, sufficiently accounts for the errors of angle, but it does not do much for the errors of distance. It can do nothing at all, as it seems to me, except where the two errors have opposite signs. This is the case with the observations in general lying between 44° and 30°; but these are so near the node that, while perturbation would have the maximum effect there as to angle, it could but slightly modify the apparent distance. Whatever greater effect it might have upon distance in the case of observations made subsequently to 1886, it would be in the wrong sense, and only tend to increase the errors.

Taking into account all the observations, and comparing with them the computed places, the perturbations divide themselves into four periods, and may be summarized as follows:

Period.	Culminating Epoch.	Maximum Purterbation.	
		°	″
18— to 1865	1864	+ 0.3	− 0.05
1865 to 1879	1871	− .4	+ .10
1881 to 1886	1883	+ .5	− .25
1886 to 18—	1890?	− 3.0?	− .20

The errors of the first period may perhaps be neglected, as the measures are very conflicting. Those of the second may be sufficiently accounted for on the theory of simple deflection from the plane of the orbit. In the third period the error of distance is too great, considering the nearness to the node, to be explained on that theory alone. It needs to suppose a divergence inward, preferably toward the center of the orbit, as the error of angle is plus. In the fourth period, where both sets of errors are minus and so considerable, we must also suppose a deviation toward some point within the orbit, in this case in the direction of the principal star, preferably even more obliquely.

A third member of the system seems to be indicated, having a period of some 20 years, motion retrograde, the plane of whose orbit cuts that of the one we are considering at about 30°, where the disturber appears to have passed in 1886, at a distance from Sirius of 4″ or 5″. The disturbances noted may also be complicated by a massive satellite of the companion, moving in an orbit commensurate with this grandiose system.

But I leave these difficulties to those who are better able to explain them. It remains to give some account of the method pursued in working out the orbit. It is substantially the graphical method set forth in "A Handbook of Double Stars." A few modifications have been made, to which I will call attention, as they have proved very convenient in practice. Practically, approximations are mostly made by working *from* the drawing, rather than up to it; extending it here or contracting it there by the thickness of a line; so for convenience as well as for precision it is desirable to have the measurements oftener than once in 10°. Direct measurement is far better, on the score of simplicity and ease of modification, than the round-about way of fixing the positions by means of the sines and co-sines of the angles. Arranging the angles with their epochs at intervals of 5°, I lay off the distance at the middle intervening points, so saving all the bothersome labor of "smoothing the curve" analytically, which is

often labor sadly lost. Of the first and the final position taken, I have already spoken. The intervening checks most depended on, the measures of angle to which I have been able to bring this calculation nearest, may be noted here. They are Bond's for 1862.19, O. Struve's for 1864.22, Dunér's for 1869.20, (which coincides exactly) for 1873.22 and for 1875.19; Hall's (Washington Observatory), 1872.24, 1876.10 and 1878.10; Stone's (Cincinnati Observatory), 1877.10, Burnham's, 1884.19 and Young's, 1887.14.

Following is the table, which, I think, sufficiently explains itself. The second part, covering a period of no observations, has the measurements only at intervals of 10°.

η	t	Δt	$\frac{\Delta t}{\Delta \eta}$	$50\sqrt{\frac{\Delta t}{\Delta \eta}} = d$ in seconds.
84	1862.450			
		2.036	.4071	10.090
79	1864.486			
		2.238	.4476	10.580
74	1866.724			
		2.416	.4832	10.990
69	1869.140			
		2.536	.5072	11.260
64	1871.676			
		2.568	.5136	11.365*
59	1874.244			
		2.536	.5072	11.260
54	1876.780			
		2.399	.4798	10.950
49	1879.179			
		2.180	.4360	10.440
44	1881.359			
		1.921	.3842	9.800
39	1883.280			
		1.647	.3294	9.075
34	1884.927			
		1.388	.2776	8.330
29	1886.315			
		1.143	.2286	7.560
24	1887.458			
		.942	.1884	6.860
19	1888.400			
		.774	.1548	6.220
14	1889.174			
		.637	.1274	5.640
9	1889.811			
		.528	.1056	5.137
4	1890.339			
		.441	.0882	4.692
359	1890.780			

* The extreme distance being at this point, this measure exceeds by .034 the mean distance which enters into the calculation.

θ	t	$10\left(\frac{d}{50}\right)^2$	$\left(\frac{d}{50}\right)^2$	d
359	1890.780			
354			.0687	4.147
344			.0516	3.592
334			.0407	3.188
324			.0334	2.890
314			.0287	2.680
304			.0260	2.550
294			.0242	2.460
284			.0234	2.420
274		6.044	.0234	2.420
264			.0246	2.470
254			.0259	2.545
244			.0283	2.660
234			.0316	2.810
224			.0356	2.985
214			.0400	3.185
204			.0461	3.395
194			.0522	3.610
189	1896.824			

From this table anyone who cares to can readily construct the apparent orbit, and, drawing it large, reduce proportionately the amount of error in the representation. It should have at least an inch to the second. Observe that the distance measures in the first part are at 81°.5, 76°.5, 71°.5, &c.

The elements of the actual orbit derived from this are:

Semi-axis major	7″.65
Eccentricity	0 .6222
Position of node	34° 40′
Inclination	40°
Position of periastron	221°.03
Periastral passage	1894.5
Period	50.125 years.

The elements of the apparent orbit are:

Length of major axis	14″.25
Length of minor axis	9″.75
Angle of major axis	53°.50
Angle of projection of periastron	248°.38
Distance of star from center	4″.29

Many orbits of this object have been cast since its discovery in 1862. With only one of these will I now compare the above result, and that one is the marvelous achievement of Auwers in 1864, uninfluenced, we must suppose, by the few observations of the companion which had then been made, and depending wholly on the displacement of Sirius which had been noted in the preceding years. His elaborate computation gave to the orbit an eccentricity of 0.6010, which is not far from that given above. He made the period 49.418 years, and set the time of periastral passage at 1793.89. Add to this date the time of two revolutions according to my elements, and you have 1894.14, which is surprisingly close to the time of periastral passage I have given.

There is a very direct method of arriving at the period to which I wish to call attention in conclusion. Draw a line from the position of the companion, as seen, October, 1896, through the center of the ellipse, bisecting it; connect the extremities of this line with the point occupied by the principal star, forming a triangle, of which calculate the area. The bisecting line cuts the ellipse at the angle 51°.45. Computing from the above table the time of passing that point we find it to be 1878.034. So in 18.79 years the radius vector has swept one-half the area of the orbit less the area of the triangle. From this the time in which it will sweep the whole area is easily arrived at.

Assuming Gill's parallax of 0″.38, the mass of the pair is three and one-fourth times that of Sun and Earth.

THE LOWELL OBSERVATORY IN MEXICO.

A. E. DOUGLASS.

For Popular Astronomy.

During the winter of 1894-5 observations at Flagstaff were made on every clear night and on the average the seeing was very poor, a condition attributed to the presence of snow. It was therefore deemed advisable to try a more southern latitude for this present winter. Not knowing with any certainty the relative merits of different parts of the Republic of Mexico, the City of Mexico was decided upon as affording the best combination of convenience and southern latitude.

At the time of my arrival in the City of Mexico on the 7th of November, it was full time for the weather to be changing from the wet to the dry season but for a month afterward rains were of almost daily occurrence and the test of the localities were not as complete as hoped. The points examined were the hill of Guadalupe, four and a half miles north of the city, and the slope rising to the west of Tacubaya, a suburb of Mexico, about an equal distance west. Each point was somewhat less than 150 feet above the level of the streets of Mexico. There seemed little reason to suppose either one better than the other, astronomically; so with a view to accessability a location in Tacubaya was chosen some 250 feet north of the stage road which passes over the mountains to Toluca and an equal distance west of the new Cuernavaca railroad. The spot was on the finca belonging to Senores Jose A. Bonilla and Juan Martinez del Cerro who most courteously charge no rent for the use of the land. It is half-a-mile south of the Mexican National Observatory and is separated from it by a small ravine.

An English carpenter was engaged on the 20th of November and rough plans of the walls of the dome put into his hands. As much of the timber had to be cut to the curve of the walls—a 20-foot radius—it was on Tuesday, the 24th, that the material reached the site and work began. The land was levelled and the first actual timbers were put in place on Wednesday afternoon. On Saturday, the 5th of December, the walls were finished and everything ready for the arrival of the telescope and dome save the leveling of the track upon which the wheels supporting the dome, were to move.

On the late afternoon of the 9th of November the lens was removed from the telescope in Flagstaff and the work of dismounting immediately begun. This and the carting required eight days. Through a mistake in the size of the railroad car it took four days to pack the heavy weights and awkwardly shaped pieces, and one roof-piece and the wooden shutters had to be left behind. The canvass shutters, described below, were substituted here in Mexico. The car left Flagstaff on the early morning of the 22d.

In order to get the Observatory material through the Custom House Mr. Lowell had corresponded with President Diaz during the summer, and the Mexican Government had with great courtesy issued an order to allow the dome (newly made in Flagstaff) and the telescope and personal baggage of the observers to pass through free of duty. On entering Mexico Dr. See carried with him a library of about three hundred volumes and these were held, the custom officers declaring that books were not included in the order issued. So after waiting a day he left them behind and came on to the city, reaching here on the 17th. On the 19th, as the books had not yet come through, and as we knew quite well that it was the purpose of the government to render us every possible aid, Dr. See drew up an application to the government to pass without delay everything that pertained to the Observatory or its work and we presented it to the Secretary of the American Legation. He forwarded it at once to the proper officials and the next day a telegram was despatched to the frontier conveying an order which seemed to cover everything. The promptness and courtesy of the Mexican Government in this act certainly could not be surpassed and I gladly take this opportunity of expressing thanks to them.

After three days detention by the local officials the car passed on the 28th of November and arrived in Mexico on Saturday, December 5th. It had then to be inspected at the City custom house but through legal details this could not be done until Mon-

PLATE XLVII.

1. From Observatory Site, looking east towards Mexico.

2. Laying the sill.

3. Centering the walls.

4. Finishing the walls.

5. The finished Walls.

6. Pulque for the men.

7. Unloading the car.

8. The rafters in place.

LOWELL OBSERVATORY IN MEXICO

day morning. Through the kindness of the Sub-Secretary of the Treasury a special inspector was sent from that department with instructions to get the car through as early in the day as was desired. The inspection accordingly was extremely brief and we were not obliged to remove the goods from the car, a privilege of great value to us as such a proceeding would have cost several days of valuable time as well as danger to the instruments and dome. In the entire transportation both the Sante Fe system and the Mexican Central Railroad made reductions in their customary rates, for which we desire to express our obligations.

Mr. M. S. McKay, General Manager of the Mexico, Cuernavaca and Pacific R. R. was also most kind to us. He not only allowed the car to be stopped for seven hours at the point on his road nearest the Observatory site but loaned us bridge timbers for making a platform upon which the heavy weights might be left so that the unloading could be done even more rapidly. At the unloading, which took place on December 8th, we had a gang of fifteen Mexican laborers under the direction of Mr. France, our carpenter, besides Mr. Sykes and the observatory assistants. The entire unloading of nearly seventeen tons of material exceedingly difficult to handle, was accomplished between half past eight and one o'clock. At intervals a glass of pulque, the National drink, was passed to the native workmen in order to keep their energies alive. From that day on we were engaged upon the work of mounting the telescope and dome.

A few days later, while carting the sections of the pier to the dome, we had an unfortunate accident which we much regretted but which, under circumstances like ours, when skilled labor is very difficult to procure, sometimes cannot be prevented. A man brought out a cart from Mexico to carry the heavy iron castings the 300 feet from the platform to the dome. He asked an exorbitant price and then showed himself not only an incapable workman but an ignorant driver. He was undoubtedly intoxicated. At noon he proceeded to do more drinking and almost the first thing in the afternoon fell from his wagon and was killed. Strange to relate, and I think through the care of the police, neither widows nor orphans have applied to us for money on the plea of keeping themselves alive. No one seemed to know where the man lived.

The telescope was mounted without trouble of any kind but the dome took longer than we expected. An entire week was consumed in leveling the double track on top of the walls and in

fitting together the sections of sill and putting on the various iron bands, so that we had a long wait before seeing anything appear well above the top of the walls. At length on December 16th the first rafter was raised into place and secured. Several days were taken in putting in the remaining uprights and rafters and in running slats around the walls upon which one could climb to the roof, but which later were destined to support the canvas. On the 21st the roof pieces were raised into place. Left by ourselves, through the departure of Mr. Sykes, on the same day, the canvas was put in place, in the course of a week, the roof was soldered, the floor put in, the observing chair put together, the arrangements for turning the dome put on and the shutters mounted. A gallery was put around the inside of the walls to give access to the wheels and machinery of the dome, doors made, ladders put in place, and innumerable little things finished neccessary to the running of an astronomical institution. At last on the afternoon of December 28th, seven weeks from the day of dismounting, Mr. Lowell brought the great lens out in a hack and it was placed in the telescope just before dark. With a very minimum of adjustment it gave excellent images.

We felt that much was accomplished when at last the lens was in place and we could get observations. Our hopes of being ready for the opposition of Mars were disappointed, so Mr. Lowell had deemed it prudent not to mount the lens until work had so far progressed on the dome that the lens was never endangered. The dome was, by the 28th, so nearly completed that it was safe to use the telescope, but much testing and adjustment of the turning apparatus remained to be done so that it was not until January 18th that it revolved satisfactorily. This result was delayed by the fact the affective work could only be done in the mornings because the dome was in use for the rest of the day and evening.

The Dome.

The dome was designed and built by Mr. Godfrey Sykes during October and half of November. It is framed entirely of wood and having an outside diameter of 42 feet is probably the largest wooden dome in the world. It gives a clear radius of 20 feet in every direction from the centre of the motion of the telescope. In some general points it resembles the new Edinburgh dome which is smaller and of iron; but in its construction Mr. Sykes showed remarkable originality in adapting to his ends simple and ready-made mechanical appliances and for such work deserves great credit.

The general plan of the dome is as follows. The lower walls of the building are surmounted by two complete concentric circles separated by something over three inches. The wheels which support the dome are about a foot in diameter and made in one solid piece with a heavy two inch axle. The wheels, twenty in number, pass between these circles and their axles rest upon them, the wood of each circle being guarded by a track of 1 x ¼ inch iron placed horizontally and bent to curve. The dome resting upon the circumference of the wheel moves about seven times as fast as the wheel so that in addition to absence of friction between surfaces, resistance due to uneveness of the track, is minimized.

The sill of the dome has a core of wooden boards screwed together and beneath them a plate of 4 x ½ inch iron, bent to curve, which serves as an upper track for the wheels to run on. On each side of the sill are vertical bands of iron and in addition, on the inside, an angle iron is placed to aid in general stiffness. Its horizontal half passes immediately beneath the guide wheels and makes a safety catch in case of wind raising the dome. The superstructure is in general drum-shaped but with the walls not quite vertical and the roof well inclined. To support this immense roof and yet allow the necessary length of open shutter the framing had to be carefully planned. The sides of the shutter are two immense rafters six feet apart in the clear, which pass entirely over the building from side to side. The upper end of the shutter is marked by a heavy cross beam some four feet beyond the apex. Beyond this beam the roof is boarded and covered with painted canvas. At the centre and highest point of each big rafter smaller rafters, cross-braced to studding, divide the roof into triangles of approximately equal size. Each triangular space is fitted with a roof piece made of very light wood and covered with tin. With strips of tin soldered over the intervening cracks the roof becomes as one piece and increases the strength of the structure. The walls of the dome are simply of light canvass tacked to slats passing aronnd the dome.

The shutters are sheets of canvas suspended on wires. One shutter passes from the apex to the eaves and another from there down. When closed they meet at the eaves and shut out the rain and when open one moves to the apex and the other to the sill. For turning the dome a rope passes around outside the sill and is tied at the shutter. At the north northeast point, as being the point least likely to be used, it takes two turns around a drum whose circumference is of a shallow V-shape. By carefully feed-

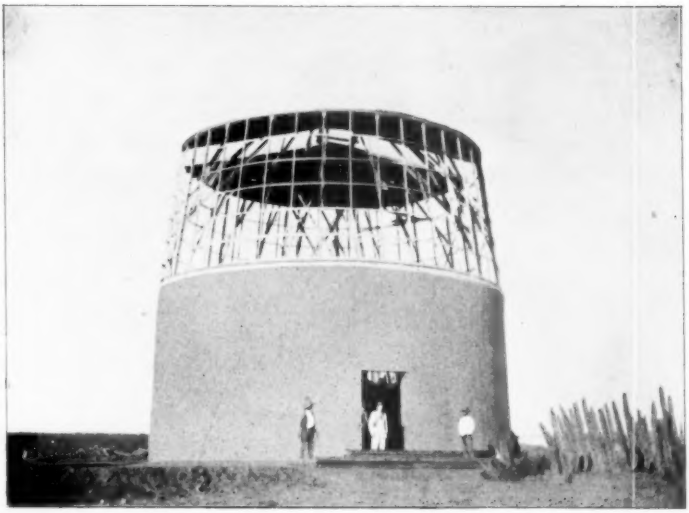
ing the rope onto the drum by proper guides the rope never gets crossed on itself. The axle of the drum passes inside the dome where it supports a six-foot wheel around which an endless cable is suspended reaching to the floor. Upon pulling this cable the dome turns. The weight of the dome is a little over four tons.

As a result of the trial of the dome two features not in the original plan, were added. A large proportion of the weight of the roof falls on the two big rafters, and notwithstanding the bands of iron, the sill spread a trifle in their direction. This was corrected by a heavy iron band, 3 inches by ⅜ inch, with three large turn buckles, passing entirely around the sill and in the longest diameter passing outside four horizontal struts, two and one-half feet long, which butt against the bases of the big rafters. This drew the dome into shape with perfect ease. It was found necessary to support the band at intervals of about four feet on small blocks of greased wood to act as rollers and allow the strain to distribute itself properly without having friction interfere to any extent.

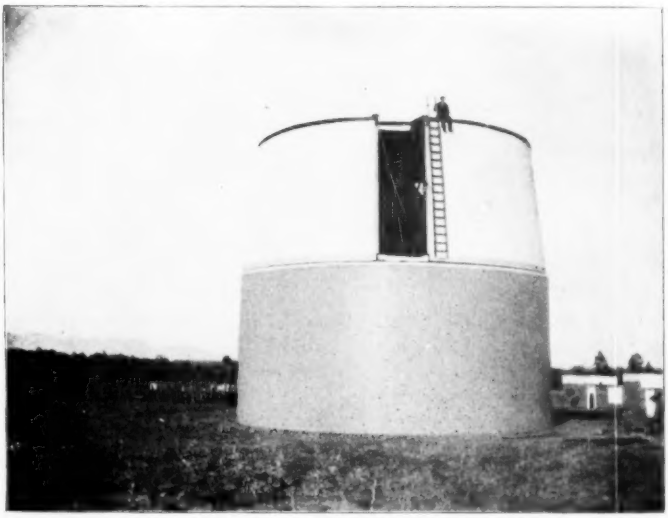
The other feature was this. To insure the more perfect running of the dome by firmly holding and directing the wheels which support it, these wheels were turned into a live-ring by connecting them all into one solid circle. Castings were made and bored to fit onto the ends of the axles of the wheels and boards were cut into a suitable shape to rest between the wheels and be bolted to the castings. Special arrangements were made for the ends of the axles toward the centre of the dome, so that the direction of the wheel could be adjusted. In this manner the wheels can be trained in line and retained there with considerable accuracy.

The telescope of the Lowell Observatory needs little more than mention. Its aperture is 24 inches and the focal length 31 feet. Its general style of construction is so heavy that it is probably one of the steadiest, if not the steadiest, in the world. The massive iron pier twelve feet high weighs five and one-half tons. The mounting of the lens from the bed-plate upward weighs seven and one-half more. The polar axis alone weighs twelve hundred pounds and in placing it in position has to be handled with the greatest nicity while the driving wheel and the declination case are being fitted on. The counterpoise consists of five cylindrical weights of four hundred pounds each. In Flagstaff, in July, this instrument was carted a mile from the station to the Observatory and set up ready for the lens in one week. Here in Mexico work on the dome was carried on at the same time so that the telescope was not ready for the lens until some two weeks had

PLATE XLVIII.



9. Dome: looking west: showing framework.



10. Dome, finished: looking east.

LOWELL OBSERVATORY IN MEXICO

elapsed but the total time actually put on it was even less than in Flagstaff. This was surprising considering the labor which we were able to employ. The work was directed by Mr. Sykes of Flagstaff.

LOWELL OBSERVATORY, Mexico, January, 1897.

PHOTOGRAPHS IN THE STUDY OF ASTRONOMY.

WM. W. PAYNE.

Teachers of astronomy having some experience know the value of good illustration in effective instruction, either in the elements or in the higher branches of science. The reason for this is plain enough, when a person realizes how he gains knowledge and retains it for effective uses. The kind of impression the mind receives in its effort to make any knowledge its own is all important. Weak impressions easily fade, and they may soon entirely disappear; stronger ones last longer, but powerful ones are probably never entirely lost from the resources of one's mental energy. A student may commit to memory a score of useful facts about the planet Jupiter, and he may be able to recite them all to a teacher, in order, clearly. What is the gain, much or little? It *may* be either; but the probability is that the real gain to the student from such an exercise will be very small. If he should carefully think over these facts about the planet, and in some way relate them in a consistent whole according to some interdependence which he can comprehend, the student has then taken independent mental steps of his own and some gain is a consequence. If he should try to make a picture of the planet on paper, representing only such things as these known facts convey to his mind, he would certainly be aiming at a better state of knowledge of Jupiter than either of the preceding steps singly imply. Memory exercises are right and necessary, but the quality of knowledge gained from such mental work only is comparatively of low order. Patient thought in relating facts, based on conscious reasoning power is a higher level of mental effort. Clear and definite expression of one's own processes of thought and the conclusions derived from them are most vital things in mental growth.

The ways of illustration in the study of astronomy are many and varied. Modern text-books of recognized authority are written by able scholars in the science, and useful illustration in them is abundant. A student of ordinary ability will generally

find llttle difficulty in comprehending the meaning of best authors who have prepared books on descriptive astronomy.

But it is more particularly the purpose of this brief article to call attention to the special advantages of good photographs or lantern slides made from photographs, in the study of many celestial objects. Most of our readers already know that the art of celestial photography is of recent origin. Even as late as 1889, very few astronomers, if any, knew certainly how to make proper exposures of the sensitive plate, so as to obtain useful results during the total solar eclipse of that year. Probably seven-eighths of the photographic work done by expeditions to California to photograph that eclipse was useless on that account. It will be remembered that, at that time, the very sensitive plates necessary to such work as well as some other had come into the hands of the astronomer only a little while before, and he lacked the experience in their use which he has since well and fully learned.

For the last eight years celestial photography, as a means of original work in astronomy, has been pursued vigorously, widely and very successfully. Its progress has materially affected every important branch of astronomy both new and old. Chiefly on account of this fact, it has been necessary to revise the best text-books of astronomy not yet ten years old, in order to keep pace with the progress of the science in essential things. We have ourselves been impressed very strongly with the marvelously rapid growth of knowledge lately, from the fact that we have had at hand an excellent 16-inch telescope whose visual power is equal probably to the best of its size anywhere, judging from some very satisfactory tests in double star work; also from the fact that we have had an 8-inch photographic telescope and a 6-inch photographic camera, which have given us like favorable advantages for the study of celestial ptolography. With this fine modern equipment it has been easy to follow, essentially all important, recent astronomical work done anywhere in the world, and to reproduce some of it by our own instruments at Goodsell Observatory to give us impressions of an original kind for uses in our post-graduate courses in astronomy and mathematics. With such facilities it has been comparatively easy for us to get many good photographs of celestial objects now under special observation and study at other Observatories, and to make from them first rate lantern slides for the use of teachers and lecturers. Those who have used such means of illustration for instruction in astronomy do not need to be told of the super-

ior advantages of such helps in conveying correct and lasting impressions concerning some features of interest that can not, at present, be gained in any other way.

Another advantage of good photographs or lantern slides is found in the fact that they often show more detail in some objects under study than is otherwise possible, thereby leading to discovery and increase of knowledge. This is so because the highly sensitive photographic plate will record impressions plainly from very faint light sources if the exposure be made sufficientiy long to allow the feeble light rays to work on the gelatine film. The natural eye will work to the limit of its power of vision in a very few minutes at most, while the sensitive film will record more and more as time goes on under favorable circumstances. This is why the photographic plate will record more, in some ways, than the best eye can see in the best telescope yet made. It is easy to illustrate this fact by referring to discoveries recently made by the aid of celestial photography. The Pleiades cluster of stars is a fair example. Only a few years ago good observers were in dispute whether or not the Merope star of the cluster had about it a nebulous veiling something like the tail of a comet. Some claimed to see it by the aid of a two-inch telescope, others could not see it all with much larger instruments, and still others firmly held there was no such nebula belonging to the star. This was true in 1882 after E. E. Barnard had observed the nebula, made a drawing of it with brief description which was published in the *Sidereal Messenger*, Vol. I, page 34. Later when photographs of the Pleiades were made by a score or more competent observers the Merope nebula was one of the easy features to trace on the negatives and its general outline was in accord with the drawing made by Mr. Barnard. Not only was this point of dispute settled by the photographic plate, but much more of very great interest was revealed by later long-exposure photographs pertaining to the whole field to this same cluster which was not previously known at all. We have reference to nebulous masses clinging to other stars of the group as well as to Merope, whose mottled and streaked formations are so plain that any one must say that they belong to the star group and are not in space beyond. This fact was seen to be significant in tending to settle an important matter, as to the order of distance in which some nebulæ stand in relation to bright or faint stars. Similarly startling things have been brought to light by the aid of photography in regard to many other celestial objects,

such as star clusters, nebulæ, whole constellations, as Orion, parts of the Galaxy, the discovery of asteroids, variable star spectra, the cloud-like forms in dense star fields and many others which we have not now space even to name.

In view of these facts, it seems to us, that high schools and academies everywhere might be greatly aided in their work in the class room by a well selected supply of mounted ptolographs and lantern slides for constant use in the reference library, accessible both to teachers and to students where their number and advancement are sufficient to warrant the small outlay of money necessary to obtain them. Colleges and some state normal schools already have such apparatus, and many institutions make free use of the stereopticon in this kind of illustration.

Those in charge of this photographic work at Goodsell Observatory can furnish these photographs and lantern slides from original negatives taken at this Observatory and also from photographs secured from other observatories to a limited extent. Attention is called to an advertisement relating to this matter found near the end of this number.

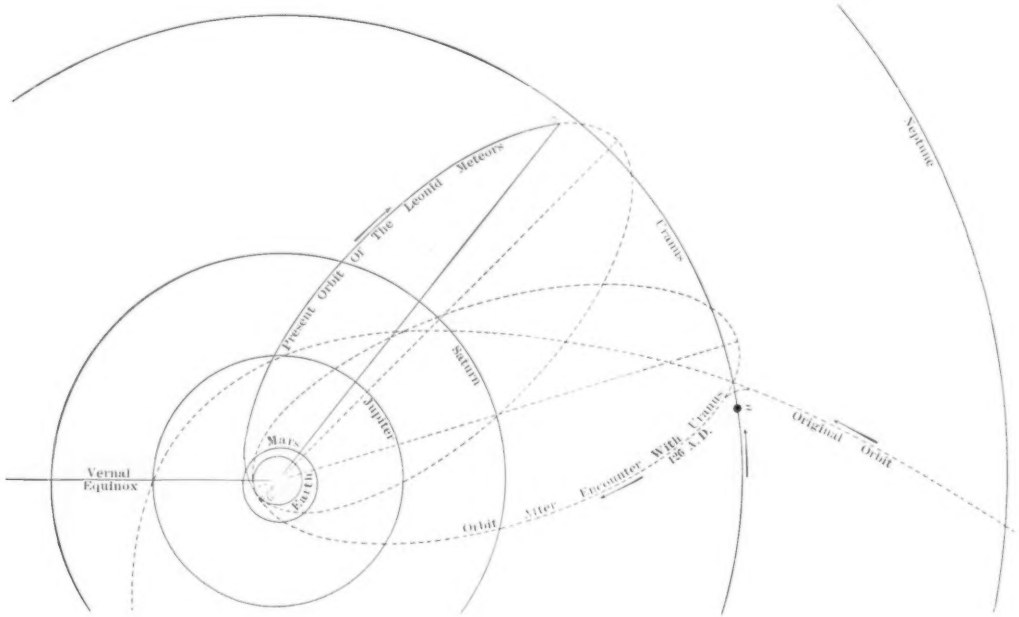
THE LEONIDS

ANNE S. YOUNG.

For Popular Astronomy.

The earliest historical mention of the Leonid meteoric shower is made by Theophanes, who wrote that in the year 472, A. D., the sky at Constantinople seemed to be on fire with falling stars. There is also a record that on the night of October 19th, 902 A. D., as the Morrich king, Ibrahim Ben Ahmed lay dying, the stars fell from heaven like rain, and in Arab chronicles this year is referred to as the "Year of the Stars." Since that time it is supposed that 29 of these showers have taken place, 12 of which are actually recorded. Professor Newton was the first to make a systematic study of these records, and showed that the periodic recurrence would be consistent with any one of five periods, viz: 180^d, $185^d.4$, $354^d.6$, $376^d.6$ and 32.25 years. He was inclined to favor an almost circular orbit with a period of 354.6 days, but suggested that the question could be definitely settled only by the determination of the perturbing effects of the planets. The gradual change in the date of showers which had occurred *Oct 19*, 902 and *Nov. 12*, 1833, indicated a slow motion in longi-

PLATE XLIX.



THE ORBIT OF THE LEONID METEORS AS CHANGED BY THE ATTRACTION OF URANUS

tude of the line of nodes of the orbit amounting to an annual change of 52″.6 with reference to the stars. Adams, following the suggestion, found that the combined influence of Jupiter, Saturn and Uranus ought theoretically to cause a change of 28′ in a period of 33.25 years, agreeing very closely with the 29′ actually observed, and proved that the period of 33.25 years must be the correct one.

The accompanying diagram is drawn to scale from elements calculated by Adams, and published in Chamber's Astronomy. Leverrier's hypothesis is that the meteoric swarm was drawn into our system in February or March of the year 126 A. D., when Uranus was in the position shown in the diagram, the orbit being changed from a parabola to an ellipse. The dotted ellipse represents the first position, the other ellipse the position of the orbit at the present time.

The densest portion of the meteoric swarm should have been at aphelion in 1885 and will probably be encountered by the Earth in 1899. As the meteors require more than a year to pass the point of intersection with the Earth's orbit, it may happen that there will be a meteoric shower in two successive years. This occurred in 1866 and 1867. Indeed, a greater or less number of meteors is to be seen on Nov. 13th of any year, for there are stragglers along the entire orbit. Even if the motions of the various members of the meteor-swarm had originally been identical, the influence of Uranus in the year 126 A. D. would have destroyed the identity, the nearer meteors being attracted more than those at a greater distance. The rates of motion being no longer the same, the meteors would gradually spread themselves over the entire orbit. Careful observation will no doubt reveal interesting facts concerning this dispersion.

The Leonids belong to the number of meteor-swarms associated with a comet. Oppolzer's elements of Tempel's comet of 1866 give the same orbit for the comet that Leverrier had computed for the meteors, and the connection between the two has been established almost beyond a question.

GOODSELL OBSERVATORY, Feb. 15, 1897.

WHERE DID MARS GET ITS MOONS?*

E. MILLER.

FOR POPULAR ASTRONOMY.

The inclination of the orbit of Aethra to the plane of the ecliptic is 25°, a little greater than the Earth's obliquity. Now, when

* Continued from page 428.

Mars is nearest to the Earth at the time of most favorable opposition, the planet is distant from the Sun 128 millions of miles, and when farthest from the Sun, Mars is 154 millions of miles distant. But the inclination of the orbit of Mars to the plane of the ecliptic differs considerably from that of the asteroid, Aethra. Let us compare the distance of Mars when farthest from the Sun, with the distance of Aethra when nearest the Sun, and ascertain, if possible, the probable results of such an investigation. The following table of the elements of the orbit of Mars as given by Holden, and the corresponding one for the asteroid, Aethra, compiled by Mr. D. P. Todd, of Amherst College, will assist in reaching a conclusion.

Nearest the Sun, Mars is 128 millions of miles distant, Aethra 149 millions.
Farthest from the Sun Mars is 154 millions of miles distant, Aethra 333 millions.
Eccentricity of orbit of Mars is 093. Of Aethra .38.
Inclination of orbit of Mars is 1° 51′. Of Aethra 25°.

The great eccentricity of the orbit of Aethra as compared with that of Mars, taken in connection with the nearest distance of Aethra to the Sun, and that of Mars when farthest, will show that if the two orbits were in the same plane, that of Aethra would intersect that of Mars at two points, and at various times, once certainly when Mars would be passing aphelion, and the asteroid, perihelion. The accompanying figure will illustrate the supposition, the plane of the paper representing the plane of the orbits.

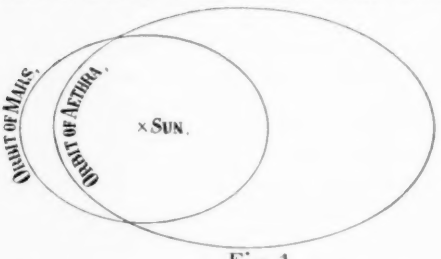


Fig. 1.

Any where to the right of the Sun's place, Mars would exert a tremendous pull on the asteroid and especially so at the points of intersection. But as the orbit of the asteroid cuts the plane of the ecliptic at an angle of 25°, and that of Mars at an angle of 1° 51′, then the probability that the planet and the asteroid will pass through the plane of the ecliptic at the same, or nearly the same time, and at points relatively the same, as if both moved in the same plane, will be somewhat diminished, but far from vanishing.

In Fig. II the plane of the paper represents the plane of the ecliptic, the large ellipse the plane of the asteroid's orbit, and the small ellipse the plane of the orbit of Mars. It is clear that not-

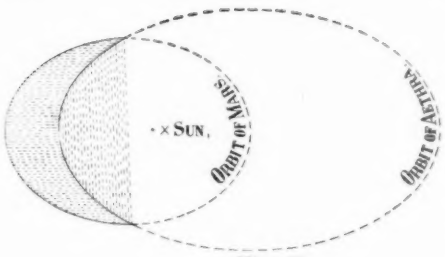


Fig. II.

withstanding the great difference between the angle formed by the intersection of the orbit of the asteroid and the plane of the ecliptic, and that by the intersection of the orbit of Mars and the plane of the ecliptic, there will come a time when the planet and the asteroid will get very near each other. Then the attraction of Mars, at such close range, will be sufficient to change forever the direction of motion, and the plane of the orbit of the asteroid. What will then be the fate of Aethra? Under the conditions named, the asteroid will be transformed into a moon revolving about Mars as its primary, and so constituting one of the family of the planet.

How many asteroids there are, or what the width of the asteroidal belt is, it may be considered probable that there are hundreds and perhaps thousands of them, so small as to be invisible even with the best telescopes, many of which move in orbits quite adjacent to the orbits of both Jupiter and Mars. Not only may some of them become satellites of the two planets, but there may be satellites of the two invisible as yet, that were once asteroids pursuing their way around the Sun influenced by the purturbing influences of either Jupiter or Mars. The asteroidal belt may, for all we know, extend all the way from the orbit of Mars to that of Juriter and the liability that some of them should be captured by their giant neighbors becomes almost, if not altogether, a certainty.

Then if all of the foregoing be true, it may be affirmed with a reasonable degree of probability that the two moons of Mars, Deimos and Phobos, at one time in the far distant past, were members of the asteroidal group. Their size also seems to indicate their origin, one of which, the larger being not more than 16 miles in diameter, and possibly only seven miles. The time of revolution of Phobos the inner moon is $7^h\ 39^m$. That is to say it revolves about Mars a little more than three times every 24 hours, and presents all the different phases of new moon, first quarter, full moon and last quarter, at each revolution. Young says that "this rapidity of revolution raises important questions as to the theory of the development of the solar system, and re-

quires modification of the views which had been held up to the time of their discovery. If the nebular hypothesis is true, a shortening of the satellite's period or a lengthening of the planet's day must have occurred since the satellites came into being." Now a shortening of the satellite's period of revolution, indicates that its orbit has been contracted to smaller dimensions, and this shortening may have been going on for a long time, so that at the time the shortening began the satellite was far enough away to be in the zone of asteriods, in fact, an asteroid itself.

The conclusion, therefore, which was referred to in the beginning of this discussion, is, that owing to the proximity of the asteroidal belt; the intersection of the orbits of Mars and Aethra; the small size of the asteroids and the moons of Mars, the red planet captured its moons from the asteroidal group. And if this be so, then Jupiter some time in the past has done a like thing.

The future, supplied with more powerful telescopes and appliances may reveal to our gaze more moons still revolving about the two planets, of which some were captured, and since that time have been playing the role of satellites.

THE UNIVERSITY OF KANSAS.

SOLAR ECLIPSES. (*Continued.*)

J. MORRISON, M. A., M. D., PH. D.

TO FIND THE OUTLINE OF THE PENUMBRA OR UMBRA ON THE SURFACE OF THE EARTH.

The general solution of the fundamental equation (67) or its equivalent (68) determines the position of the penumbra and umbra on the Earth's surface at any time during which an eclipse can occur.

In this discussion we shall use the notation and methods of Bessel as adopted by Chauvenet, but will enter into more details and give some geometrical illustrations which will doubtless aid the student in studying this important and interesting subject.

Resuming equations (60) and (68) writing θ for $(\mu_1 - a)$ in the former, we have

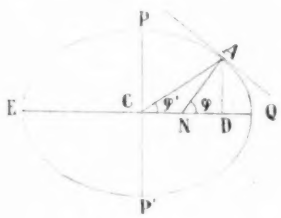
$$\begin{aligned} \xi &= \rho \cos \varphi' \sin \theta \\ \eta &= \rho \left[\sin \varphi' \cos d - \cos \varphi' \sin d \cos \theta\right) \\ \zeta &= \rho \left[\sin \varphi' \sin d + \cos \varphi' \cos d \cos \theta\right] \end{aligned} \qquad (69)$$

and

$$\begin{aligned} (1 - i\zeta) \sin Q &= x - \xi \\ (1 - i\zeta) \cos Q &= y - \eta \end{aligned}$$

These five equations contain six unknown quantities, viz., ξ, η, ζ, φ' θ and Q, the first three being the coördinates of the place at which an *apparent* contact of the limbs of the Sun and Moon may be observed; the fourth, the geocentric latitude of that place; the fifth, the hour-angle of the point Z, and the sixth is the angle PZM or the position-angle of the Moon's centre at this point. The arc ZM' passes through the Sun's centre as well as through the point of contact. At the time of an eclipse Zs never exceeds $5''$, the angle PZM may therefore be taken equal to Psm, that is the angle Q is the position angle or the angular distance of the point of contact from the declination circle passing through the apparent centre of the Sun. Any one of these six unknown quantities may be arbitrarily assumed, provided we do not assume such values as would give an impossible result. It will be found most convenient to take Q as the assumed arbitrary quantity and then deduce the other five.

In these equations there is however another unknown quantity, ρ, which depends on φ', and cannot be determined until the latter is found. We might for a first approximation neglect the spheroidal figure of the Earth and put $\zeta = 1$ and after finding an approximate value of φ', compute a more accurate value of ρ and then repeat the computation of φ'. This double computation can be obviated and the ellipticity of the Earth taken into account from the very beginning by the following elegant transformation due to Bessel.



Let $PEP'Q$ be a section of the terrestrial spheroid made by a meridian, PP' the poles and A a point on its surface; draw the normal AN and denote the geographical latitude ANQ by φ. Then if x and y be the coördinates of A, we have the subnormal

$$AD = \frac{b^2}{a^2} x = (1 - e^2)\, x, \text{ when } a = 1,$$

and
$$x \tan \varphi' = (1 - e^2)\, x \tan \varphi$$
or
$$\tan \varphi' = (1 - e^2) \tan \varphi \qquad (70)$$

the relation between the geocentric and geographical latitudes.

The equation of the ellipse is

$$x^2 + \frac{y^2}{1 - e^2} = 1$$

and
$$\frac{y}{x} = \tan \varphi'$$
$$= (1 - e^2) \tan \varphi$$

whence we get

$$x = \frac{\cos \varphi}{\sqrt{(1 - e^2 \sin^2 \varphi)}} = \rho \cos \varphi'$$

and

$$y = \frac{(1 - e^2) \sin \varphi}{\sqrt{(1 - e^2 \sin^2 \varphi)}} = \rho \sin \varphi' \qquad (71)$$

If we now put

$$\cos \varphi_1 = \rho \cos \varphi'$$

$$= \frac{\cos \varphi}{\sqrt{(1 - e^2 \sin^2 \varphi)}}$$

then

$$\sin \varphi_1 = \sqrt{(1 - \cos^2 \varphi_1)}$$

$$= \frac{\sqrt{1 - e^2} \cdot \sin \varphi}{\sqrt{(1 - e^2 \sin^2 \varphi)}}$$

or

$$\sqrt{(1 - e^2)} \sin \varphi_1 = \frac{(1 - e^2) \sin \varphi}{\sqrt{(1 - e^2 \sin^2 \varphi)}} = \rho \sin \varphi'$$

whence we get

$$\sqrt{1 - e^2} \tan \varphi_1 = \tan \varphi'$$

$$= (1 - e^2) \tan \varphi \qquad \text{by (70)}$$

and

$$\tan \varphi = \frac{\tan \varphi_1}{\sqrt{1 - e^2}} \qquad (72)$$

which gives the relation between the new variable φ_1 and the geographical latitude φ.

The Clark spheroid of 1866, adopted by the U. S. Coast and Geodetic Survey, gives $\log e = 8.9152515$, and therefore

$$\log \sqrt{(1 - e^2)} = 9.9985251.$$

The first three equations of group (69) now become

$$\begin{aligned} \xi &= \cos \varphi_1 \sin \theta \\ \eta &= \sin \varphi_1 \cos d \sqrt{1 - e^2} - \cos \varphi_1 \sin d \cos \theta \\ \zeta &= \sin \varphi_1 \sin d \sqrt{1 - e^2} + \cos \varphi_1 \cos d \cos \theta \end{aligned} \qquad (73)$$

which can be simplified by putting

$$\rho_1 \sin d_1 = \sin d \qquad \text{and } \rho_2 \sin d_2 = \sqrt{1 - e^2} \sin d$$

$$\rho_1 \cos d_1 = \sqrt{1 - e^2} \cdot \cos d \qquad \rho_2 \cos d_2 = \cos d$$

then (73) becomes

$$\begin{aligned} \xi &= \cos \varphi_1 \sin \theta \\ \eta &= \rho_1 \sin \varphi_1 \cos d_1 - \rho_1 \cos \varphi_1 \sin d_1 \cos \theta \\ \zeta &= \rho_2 \sin \varphi_1 \sin d_2 + \rho_2 \cos \varphi_1 \cos d_2 \cos \theta \end{aligned} \qquad (74)$$

The quantities ρ_1 ρ_2, d_1 and d_2 must be computed and tabulated

for the same dates as the Besselian Elements, and can then be easily interpolated for all intermediate dates.

Again, let us put $\eta_1 = \frac{\eta}{\rho_1}$ and assume ζ_1 such that $\xi^2 + \eta_1^2 + \zeta_1^2 = 1$, then the last group becomes

$$\begin{aligned} \xi &= \cos \varphi_1 \sin \theta \\ \eta_1 &= \sin \varphi_1 \cos d_1 - \cos \varphi_1 \sin d_1 \cos \theta \\ \zeta_1 &= \sin \varphi_1 \sin d_1 + \cos \varphi_1 \cos d_1 \cos \theta \end{aligned} \qquad (75)$$

The relation between ζ and ζ_1 will be required and is found as follows: multiply the second of the last group by $\sin d_1$ and the third by $\cos d_1$ and subtract the first product from the second, and again multiply the second by $\cos d_1$ and the third by $\sin d_1$ and add the results, we shall have

$$\begin{aligned} \cos \varphi_1 \cos \theta &= -\eta_1 \sin d_1 + \zeta_1 \cos d_1 \\ \sin \varphi_1 \qquad &= \eta_1 \cos d_1 + \zeta_1 \sin d_1 \end{aligned} \qquad (76)$$

Substituting these in the third of (74) gives after some simple reductions

$$\zeta = \rho_2 \zeta_1 \cos (d_1 - d_2) - \rho_2 \eta_1 \sin (d_1 - d_2) \qquad (77)$$

from which we see that ζ and ζ_1 are very nearly equal, and when very great accuracy is not desired we may use the one for the other. As the result of these transformations group (69) now takes the following form

$$\begin{aligned} (l - i\zeta_1) \sin Q &= x - \xi \\ (l - i\zeta_1) \cos Q &= y - \eta = y - \rho_1 \eta_1 \\ \xi^2 + \eta_1^2 + \zeta_1^2 &= 1 \end{aligned} \qquad (78)$$

which determine ξ, η_1 and ζ_1 for each assumed value of Q, and then (75 and 76)

$$\begin{aligned} \cos \varphi_1 \sin \theta &= \xi \\ \cos \varphi_1 \cos \theta &= -\eta_1 \sin d_1 + \zeta_1 \cos d_1 \\ \sin \varphi_1 \qquad &= \eta_1 \cos d_1 + \zeta_1 \sin d_1 \end{aligned} \qquad (79)$$

determine φ_1 and θ and thence the latitude and longitude by

$$\tan \varphi = \frac{\tan \varphi_1}{\sqrt{1 - e^2}}$$

and $$\lambda = \mu_1 - \theta. \qquad \text{(See page 317).}$$

In (78) we have put ζ_1 for ζ in the small term $i\zeta$ which can be done here without any appreciable error, but if a more accurate solution is required, we may proceed as follows. In the first two equations of (78) put

$$\begin{aligned} x - l \sin Q &= \sin \beta \sin \gamma \\ \text{and} \qquad \frac{y}{\rho_1} - \frac{l \cos Q}{\rho_1} &= \sin \beta \cos \gamma \end{aligned} \qquad (80)$$

then they become

$$\begin{aligned} \xi &= \sin\beta \sin\gamma + i\zeta_1 \sin Q \\ \eta_1 &= \sin\beta \cos\gamma + i\zeta_1 \cos Q \end{aligned} \qquad (81)$$

omitting the diviser ρ_1 in the small term $i\zeta_1 \cos Q$, because ρ_1 is always nearly equal to unity. Substituting these in the third equation of (78) we find after neglecting terms involving i^2 which are quite inappreciable

$$\zeta_1^2 = \cos^2\beta - 2i\zeta_1 \sin\beta \cos(Q-\gamma)$$

and neglecting the last term of the second member, we have for an approximate value of $\zeta = \cos\beta$, and substituting this in the last term we have

$$\zeta_1^2 = \cos^2\beta - 2i \sin\beta \cos\beta \cos(Q-\gamma)$$

and $$\zeta_1 = \cos\beta - i \sin\beta \cos(Q-\gamma), \qquad \text{approximately.}$$

It may be observed that the second member ought to have the double sign, but if the eclipse is *visible* ζ_1 must be positive, that is it must lie above the fundamental plane. Substituting these last values of η_1 and ζ_1 in (77) we have, after omitting terms involving i^2 and $i \sin(d_1 - d_2)$ as practically insensible,

$$\begin{aligned} \zeta &= \rho_2 \{\cos\beta - i \sin\beta \cos(Q-\gamma)\cos(d_1-d_2) \\ &\qquad - \sin\beta \cos\gamma \sin(d_1-d_2)\} \\ &= \rho_2 \{\cos\beta - \sin\beta \big(i\cos(Q-\gamma)\cos(d_1-d_2) + \\ &\qquad \cos\gamma \sin(d_1-d_2)\big)\} \end{aligned} \qquad (82)$$

Since i and $\sin(d_1 - d_2)$ are always very small the last two terms of the second member of (82) are also small and may be computed as follows

put $$i\cos(Q-\gamma) = k\cos K$$

and $$\cos\gamma = k \sin K$$

then we shall have

$$\zeta = \rho_2 (\cos\beta - k \sin\beta \cos(K + d_1 - d_2)) \qquad (83)$$

When this value of ζ is substituted for ζ_1 in the small term $i\zeta$ in (81), the error committed will be of the order i^3 and the solution will be practically exact.

All the quantities in the second member of (82) are known, Q being of course assumed and β and γ found from (80).

Therefore we have finally from (78) or (81) with all the exactness warranted by the original data

$$\begin{aligned} \xi &= \sin\beta \sin\gamma + i\rho_2 (\cos\beta - k \sin\beta \cos(K + d_1 - d_2)) \sin Q \\ \eta_1 &= \sin\beta \cos\gamma + \frac{i\rho_2}{\rho_1}\Big(\cos\beta - k \sin\beta \cos(K + d_1 - d^2)\Big) \cos Q \\ \zeta_1 &= 1 - \xi^2 - \eta_1^2 \end{aligned} \qquad (84)$$

And if we put $\xi = \sin \beta' \sin \gamma'$
and $\eta_1 = \sin \beta' \cos \gamma'$ (85)
we shall then have $\zeta_1 = \cos \beta'$

Substituting these values of ξ, η_1 and ζ_1 in (79) we have

$$\begin{aligned} \cos \varphi_1 \sin \theta &= \sin \beta' \sin \gamma' \\ \cos \varphi_1 \cos \theta &= -\sin \beta' \cos \gamma' \sin d_1 + \cos \beta' \cos d_1 \\ \sin \varphi_1 &= \sin \beta' \cos \gamma' \cos d_1 + \cos \beta' \sin d_1 \end{aligned}$$

which may be easily adapted to logarithmic computation thus: compute c and C from

$$\begin{aligned} c \sin C &= \sin \beta' \cos \gamma' = \eta_1 \\ c \cos C &= \cos \beta' = \zeta_1 \end{aligned}$$

then the above becomes

$$\begin{aligned} \cos \varphi_1 \sin \theta &= \xi \\ \cos \varphi_1 \cos \theta &= c \cos (C + d_1) \\ \sin \varphi_1 &= c \sin (C + d_1) \end{aligned} \qquad (86)$$

then we have

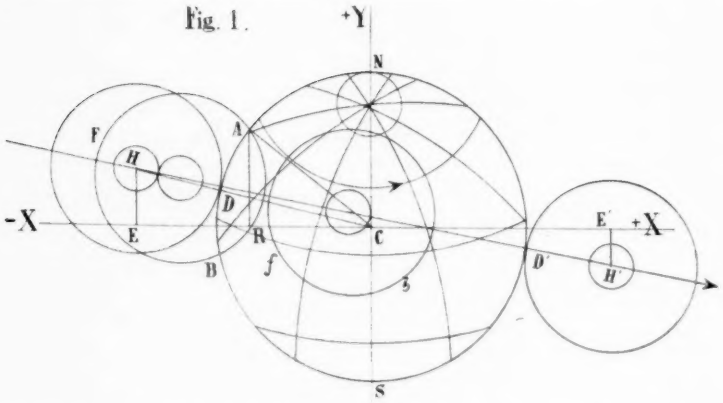
$$\tan \varphi = \frac{\tan \varphi_1}{\sqrt{1 - e^2}} \text{ and } \lambda = \mu_1 - \theta.$$

Before deducing criteria for determining whether the eclipse is beginning or ending at the places found by the preceding formulæ, we shall first determine the times and places at which the eclipse begins and ends on the Earth generally. These dates are the limiting times between which all the circumstances of an eclipse can occur.

If an observer were situated somewhere in the direction of the axis of Z and with his face towards the Earth, he would see the shadow of the Moon traversing the Earth's disk from left to right or from west to east, the Earth also turning in the same direction as indicated by the arrow heads in Figs. 1, 2 and 3.* The Sun will be rising at all points on the left or west side, that is at all points on *NDS* and setting on the east side or on *ND'S*. Let *ABF* be a section of the penumbra and the small concentric circle a section of the umbra on the fundamental plane. The first and last

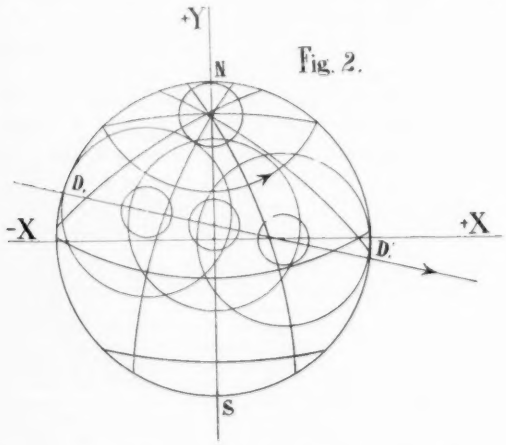
* In Schellen's Spectrum Analysis translated from the German and published in England under the supervision of one of the most distinguisned English astronomers and scientists, a page or more is taken up proving that the shadow of the Moon during an eclipse of the Sun moves across the Earth's surface from east to west!! The reasoning employed was somewhat as follows: The Earth makes a revolution on its axis in a day and the Moon makes a revolution around the Earth in about 27 days therefore a spectator on the Earth's surface must move at least 27 times faster than the Moon's shadow and of course would enter the shadow on the west side, pass through it and emerge from it on the east side or regarding for the moment the Earth as fixed, the shadow would appear to move from east to west. The writer first directed the attention of the English reviser to the error which has been corrected or rather removed altogether from subsequent editions. The solution of Problem 1 in this paper shows that the time required for the shadow to cross the Earth's disk can never exceed 7.4 hours.

Fig. 1.



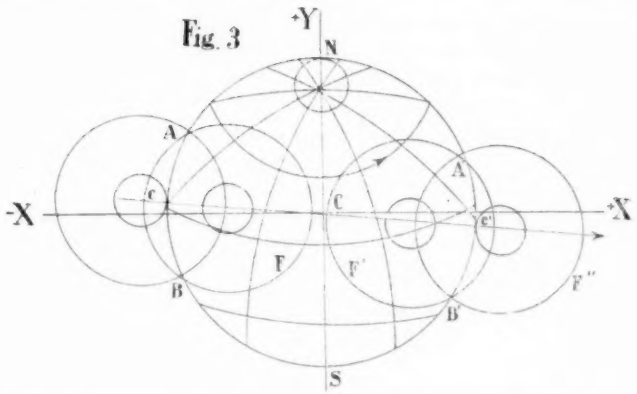
contacts are at the points D and D' respectively, Fig. 1. And we are now to find the times when these contacts take place as well as the latitude and longitude of these points. C being the centre of the Earth and the origin of coördinates CD and CD' are the radii of the Earth for these points; HD, $H'D'$ are the radii of the penumbra and CE, EH and CE', $E'H'$ the coördinates of the centre of the shadow, that is for the first contact $CE = -x$ and $EH = +y$, and for the last $CE' = +x$ and $E'H' = -y$ according

Fig. 2.



to our diagram. When the shadow has advanced a little on the Earth's disk there will be two points A and B in the horizon at which place the eclipse is beginning at sunrise. As the

Fig. 3



shadow advances, the points A and B will separate until their distance apart is equal to the diameter of the shadow after which they will approach each other as in the outline ABF in Fig. 3 and the eclipse is ending at sunrise. Since the first and last contacts and the points A and B where the eclipse is beginning or ending at sunrise or at sunset, are in the horizon and on the fundamental plane, we must have $\zeta_1 = 0$ and therefore (78) becomes

$$\begin{aligned} l \sin Q &= x - \xi \\ l \cos Q &= y - \eta = y - \rho_1 \eta_1 \\ \xi^2 + \eta_1^2 &= 1 \end{aligned} \tag{87}$$

as the conditions that must be satisfied for these places

Put
$$\begin{aligned} m \sin M &= x & p \sin \gamma &= \xi \\ m \cos M &= y & p \cos \gamma &= \eta \end{aligned} \tag{88}$$

where we see from the diagram that $m = HC$, $M = EHC$, $p = AC$, $\gamma = RAC$, $\xi = CR$ and $\eta = AR$, then (87) becomes

$$\begin{aligned} l \sin Q &= m \sin M - p \sin \gamma \\ l \cos Q &= m \cos M - p \cos \gamma \end{aligned}$$

Squaring and adding we find

$$l^2 = m^2 - 2mp \cos (M - \gamma) + p^2$$

whence
$$\sin^2 \frac{1}{2} (M - \gamma) = \frac{l^2 - (m - p)^2}{4mp}.$$

Let
$$\chi = M - \gamma,$$

then this may be written

$$\sin \frac{1}{2} \chi = \pm \sqrt{\frac{(l + m - p)\ (l - m + p)}{4mp}} \tag{89}$$

and
$$\gamma = M \pm \chi.$$

Also χ must always be taken less than 180°. The two values of γ are necessary to determine the two points A and B which satisfy the conditions (87). Formula (89) contains one unknown quantity viz., p for m, M and l are accurately known. It is easily seen that p is always very nearly equal to unity, hence if we make $p = 1$ in (89) we shall first get an approximate value of γ, and a more correct value can be found thus:

put $\xi = \sin \gamma'$, then by (87) $\eta_1 = \cos \gamma'$ and $\eta = \rho_1 \eta_1$

we have (88)
$$p \sin \gamma = \sin \gamma'$$
$$p \cos \gamma = \rho_1 \cos \gamma'$$

whence
$$\tan \gamma' = \rho_1 \tan \gamma$$

and
$$p = \frac{\sin \gamma'}{\sin \gamma} = \frac{\rho_1 \cos \gamma'}{\cos \gamma} \qquad (90)$$

And with this value of p in (89) a more accurate value of γ is found and we might repeat the computation with this second value of γ, and a still more accurate value of p may be found, but it will never be necessary to proceed beyond the *second* approximation. We remark here however, that in the *second* approximation we must use the *two* values of γ given by (89), that is, we must compute p for *each* of the *two places* (A and B) separately.

When the second value of γ is found the final value of γ' is computed from

$$\tan \gamma' = \rho_1 \tan \gamma \qquad (91)$$

and then making $\xi = \sin \gamma'$, $\eta_1 = \cos \gamma'$ and $\zeta_1 = 0$ in (79) we have

$$\begin{aligned} \cos \varphi_1 \sin \theta &= \sin \gamma' \\ \cos \varphi_1 \cos \theta &= -\cos \gamma' \sin d_1 \\ \sin \varphi_1 &= \cos \gamma' \cos d_1 \end{aligned} \qquad (92)$$

and
$$\tan \varphi = \frac{\tan \varphi_1}{\sqrt{1 - e^2}} \text{ and } \lambda = \mu - \theta$$

which determine the latitude and longitude of the two points A and B when the eclipse begins or ends at sunrise or sunset.

When the eclipse begins or ends on the Earth generally the cone of the shadow has but a single point in common with the Earth's surface as shown at D and D' Fig. 1. The two solutions of (89) reduce to a single one, and this can happen only when $\chi = 0$ and therefore we must have

$$l + m - p = 0 \quad \text{and} \quad l - m + p = 0$$

or
$$m = p + l \quad \text{and} \quad m = p - l$$

There may be four cases of contact, viz., two exterior as shown

at D and D' Fig. 1 and two interior as shown at D_1 and D'_1 in Fig. 2. In the case of the exterior contacts the axis of the shadow is *without* the Earth and we have $m = \sqrt{(x^2+y^2)} = p+l$. The first interior contact occurs at the last point on the Earth's surface where the eclipse ends at sunrise D_1, and the second at the first point D'_1 where it begins at sunset.

It is evident however that the *interior* contacts can only occur when the *whole* shadow on the fundamental plane, falls *within* the Earth's disk and then we must have $m = p - l$. Therefore for the beginning and ending on the Earth generally we always have

$$(p + l) \sin M = x$$
$$(p + l) \cos M = y$$

We must now find a time T, when these conditions are satisfied

Put $$T = T_0 + \tau$$

where T_0 is the epoch of the eclipse tables which may be the time of conjunction or a more convenient one will be the nearest whole hour to conjunction, and for which the values of x and y are x_0 and y_0.

Now if x' and y' be the hourly* variations of x and y for the term T, we will have

$$x = x_0 + \tau x' \qquad \text{and} \qquad y = y_0 + \tau y'$$

and

$$(p + l) \sin M = x_0 + \tau x'$$
$$(p + l) \cos M = y_0 + \tau y'$$

Put $\quad m_0 \sin M_0 = x_0 \qquad$ and $\qquad n \sin N = x'$

$$m_0 \cos M_0 = y_0 \qquad\qquad n \cos N = y'$$

then we shall have

$$(p + l) \sin M = m_0 \sin M_0 + \tau \,.\, n \sin N$$
$$(p + l) \cos M = m_0 \cos M_0 + \tau \,.\, n \cos N$$

Multiply the first by cos N and the second by sin N and subtract the second result from the first, and again multiply the first sin N and the second by cos N and add the results, and we get

$$(p + l) \sin (M - N) = m_0 \sin (M_0 - N)$$
$$(p + l) \cos (M - N) = m_0 \cos (M_0 - N) + n\tau$$

and if we now put $M - N = \psi$ we have

$$\sin \psi = \frac{m_0 \sin (M_0 - N)}{p + l}$$

$$\tau = \frac{p + l}{n} \cos \psi - \frac{m_0}{n} \cos (M_0 - N) \qquad (93)$$

$$T = T_0 + \tau$$

* It would be more accurate to let x' and y' denote the changes in x and y during 10 minutes instead of an hour.

The first of these gives two values for ψ, and cos ψ must be taken first with the *negative* and second with the *positive* sign; the first will evidently give an approximate time for the beginning and the second for the end of the eclipse generally.

For the interior contacts, *when they occur*, we have

$$\sin \psi = \frac{m_0 \sin (M_0 - N)}{p - l}$$

$$\tau = \frac{p - l}{n} \cos \psi - \frac{m_0}{n} \cos (M_0 - N) \qquad (94)$$

$$T = T_0 + \tau$$

When $p - l$ is less than $m_0 \sin (M_0 - N)$, sin ψ has an impossible value and the interior contacts cannot occur.

In the computation of (93) and (94) we first assume $p = 1$ and find an approximate value of ψ, then since in this case $\chi = 0$ and $\gamma = M$ by (89) we have

$$\gamma - N = \psi \text{ or } \gamma = N + \psi \qquad (95)$$

with which we find p by (90) and the second computation of (93) and (94) will give the exact times of beginning and ending on the Earth generally. In (95) we must use the two values of ψ found by taking cos ψ with both the positive and negative signs and therefore we shall find different values of p for the beginning and ending. The second approximation will require separate computations for the two cases.

When the first approximate value of τ is found we can then take the values of x, y, x' y' and l from the eclipse tables for the times $T = T_0 \pm \tau$, for the second approximation. Finally when the correct value of ψ has been found and also the true value of $\gamma = N + \psi$ for each point and also the true values of γ' from (91) the latitude and longitude of the first and last points of contact can be computed from (92).

We will close this paper by computing the beginning and ending on the Earth generally of the eclipse of July 29, 1897 using the elements of the eclipse as given an page 415 of the *American Ephemeris*. We take $T_0 = 4$ hours which is near the middle of the eclipse, and for this date we have

$$x_0 = + 0.00174 \qquad y_0 = - 0.06959 \qquad l = 0.55338$$
$$x' = + 0.08315 \qquad y' = - 0.03066$$

the variations of x and y in 10 minutes. For brevity we will only put down the results which may be verified by the student. With the above data we easily find

$M_0 = 178° 34' 4''$ $N = 110' 24' 26''$
$\log m_0 = 8.04269$ $\log n = 8.94754$ $M_0 - N = 68° 19' 38''$

For the first approximation we take $p = 1$, then

$$p + l = 1.55338 \text{ and } \psi = 177° 36' 47'' \text{ or } 2° 23' 13''$$

$$\frac{1 + l}{n} \cos \psi = \mp 17.512$$

the unit of time being 10 minutes.

$$-\frac{m_0}{n} \cos (M_0 - N) = - \ 0.290$$

therefore $\tau = -17.802 = -178^m.02 = -2^h\ 58^m.02$
and $= +17.222 = +172\ .22 = +2\ 52\ .22$
$T = T_0 \pm \tau$
$= 1^h\ 1^m.98$ beginning and $6^h\ 52^m.22$ end

The Ephemeris gives

$1^h\ 2^m.0$ " " $6^h\ 52^m.1$ "

The first approximation is therefore accurate enough for all practical purposes.

We will now proceed to the second approximation and then determine the latitude and longitude.

	Beginning.	Ending.
T_0 = approximate time =	$1^h\ 0^m$	$6^h\ 50^m$
$\gamma = N + \psi$ (95)	287° 51′ 13″	112° 37′ 39″
$\log \rho_1$ (73)	9.99868	9.99867
$\tan \gamma$	0.49201n	0.38005n
$\tan \gamma'$ (91)	0.49069n	0.37872n
γ'	287° 54′ 17″	112° 41′ 23″
$\sin \gamma'$	9.97844n	9.96501
$\sin \gamma$	9.97856n	9 96522
$\log p$	9 99988	9.99979
p	0.99973	.99953

We also have (page 415 *American Ephemeris*) for the above dates

x_0	− 1.49510	+ 1.41511
y_0	+ 0.48130	− 0.59172
l	+ 0.55362	+ 0 55297
x'	+ 0.08315	+ 0.08311
y'	− 0.03055	− 0.03076
$p + l$	1 55335	1.55250
M_0	287° 50′ 40″	112° 41′ 30″
$\log m_0$	0.19608	0 18578
N	110° 10′ 26″	110° 18′ 37″
$M_0 - N$	177° 40′ 14″	2° 22′ 53″
ψ	177 38 44	2 21 10
$\frac{p+l}{n} \cos \psi$	− 17.525	+ 17.504
$-\frac{m_0}{n} \cos (M_0 - N)$	+ 17.726	− 17.293
τ	+ 0.201	+ 0.211
	$+ 2^m.01$	$+ 2^m.11$
T_0	$1^h\ 0$	$6^h\ 50^m$
T	$1^h\ 2^m.01$	$6^h\ 52^m.11$

which agree exactly with the Ephemeris. We now proceed to find the exact value of γ and thence the latitude and longitude by (92). We first find ρ_1 and sin d_1 and cos d_1 using the values of sin d and cos d for $1^h\ 2^m$ and $6^h\ 52^m.1$

	Beginning.	Ending.
log ρ_1 (73)	9.99868	9.99868
sin d_1	9.50580	9.50454
cos d_1	9.97647	9.97661
$\gamma = N + \psi_1$ (95)	287° 49′ 9″	112° 39′ 47″
γ'	287 52 12	112 43 30
cos φ_1 sin $\theta' =$ sin γ'	9.97852n	9.96490
− cos γ'	9.48694n	9.58694
sin d_1	9 50580	9.50454
cos φ_1 cos θ	8.99274n	9.09148
tan θ	0.98578	0.87342
θ	264° 6′ 02″	82° 27′ 37″
cos θ	9.01192n	9.12273
cos φ_1	9.98082	9 96875
φ_1	16° 53′ 48″	21° 28′ 45″
cos d_1	9.97647	9.97661
sin φ_1	9.46341	9.56355n
φ_1	16° 53′ 50″	− 21° 28′ 35″
tan φ_1	9.48254	9.59488n
$\sqrt{1-e^2}$	9.99853	9.99853
tan φ	9.48401	9.59635n
φ	16° 57′.0	− 21° 32′.5
μ_1	13° 55′.6	101 29 .0
θ	264 6 .0	82 22 .6
λ	109° 49′.6w	19° 6′.4w

Therefore the eclipse begins in latitude 16° 57′ N and long. 109° 49′.6 W and ends in latitude 21° 32′.5 S and longitude 19° 6′.4 W of Greenwich.

The agreement of the two values of φ_1 is a check on the computation; both values are necessary as the sign of φ_1 cannot be determined from its cosine.

TO BE CONTINUED.

Problems.

28. If π and π' denote the equatorial horizontal parallaxes of the Moon and Sun, δ and δ' their semi-diameters and h and h' their hourly motions, show that the duration T of a solar eclipse is

$$T = \frac{2(\pi - \pi' + \delta + \delta')}{h - h'}$$

29. If the angular semi-diameter of the Earth's shadow and of the Moon is seen from the Earth's centre be d and δ respectively and the apparent angular hourly motion of the Moon about the

Earth be h, find expressions for the entire duration of a lunar eclipse and the duration of totality, the Moon being in the node of her orbit when in opposition.

30. If the angle subtended at the Earth by the Sun and the stationary point of a planet's orbit be θ and E the greatest elongation of the planet show that

$$2 \cot \theta = \sec \frac{1}{2} E + \operatorname{cosec} \frac{1}{2} E.$$

31. The R. A. and Decl. of a star being α and δ respectively and δ' = the Decl. of the Sun when they rise or set together find φ the latitude of the place.

EVENINGS WITH THE STARS.

MARY PROCTOR.

FOR POPULAR ASTRONOMY.

During the month of March, the Great Bear, is in the northeast, the Pointers indicating the Pole Star, in the constellation of the Little Bear. Coiling between the two bears east of the northern horizon, is (*Draco*) the Dragon, with its two gleaming eyes, Beta and Gamma. With an opera glass notice the rich orange color of Gamma and the white of Beta. West of north, is *Cepheus*, beside his wife Cassiopeia and near by is *Andromeda*, their daughter, and her rescuer, *Perseus*. Midway between *Cassiopeia*, and the Great Bear (*Ursa Major*), is Camelopard, an insignificant constellation. The Triangles (*Triangula*) and (*Aries*) the Ram, are approaching the western horizon, and (*Cetus*) the Whale, has almost disappeared. Towards the southwest, are the Twins (*Gemini*), and in the mid-heaven, due west, is (*Taurus*) the Bull, with its blazing eye *Aldebaran*, and the beautiful cluster known as the *Pleiades*. Above Taurus, is the Charioteer (*Auriga*), and below it is *Orion*, already slanting towards "his grave, low down in the west." He treads on (*Lepus*) the Hare, and *Eridanus* flows towards the southwest. The three stars in the Giant's belt, point to *Sirius*, in the constellation of (*Canis Major*) the Great Dog, and higher up, is the Little Dog (*Canis Minor*). In the southern horizon is a part of the great ship *Argo*, near which, low down, is the Dove *Columba*. Almost overhead, is (*Cancer*) the Crab, with the pretty cluster *Praesepe*, or the Beehive, and coiling south of it, and towards the southeastern horizon, is (*Hydra*) the Sea Serpent. Above it, are the constellations (*Corvus*), the Crow, and (*Crater*) the Cup, which are represented as resting on the serpent's back, in the old fashioned star maps. *Virgo*, the Virgin has risen due east, and midway between *Virgo* and Cancer, is the zodiacal sign (*Leo*), the Lion, with the bright, first magnitude star *Regulus*. North of *Virgo*, is (*Coma Berenices*) the Hair of Queen Berenice, and nearly due east, and between this group of stars and the Great Bear (Ursa Major) is the constellation of the Hunting Dogs (*Canes Venatici*). Northeast, the Herdsman (Boötes), is rising, distinguished by the brilliant star Arcturus.

GEMINI, THE TWINS.

This constellation is represented on celestial maps, as the twin brothers Castor, and Pollux. According to Grecian mythology they embarked with Jason in

quest of the golden fleece, at Colchis, on which occasion they distinguished themselves by their bravery. During a battle, Castor was killed, and Pollux was so tenderly attached to his brother, that he was unwilling to survive him. He therefore entreated Jupiter to restore Castor to life, or to be deprived himself of immortality; whereupon, Jupiter permitted Castor, who had been slain, to share the immortality of Pollux. Consequently, as long as the one was upon Earth, so long was the other detained in the underworld, and they alternately lived and died every day. Jupiter further rewarded their love for each other by changing them both into the constellation, known to us by the name of *Gemini*, the Twins.

Castor and Pollux.

Castor is the finest double star visible in the northern heavens, the components being composed of a second and third magnitude star and rather more than 5″ apart. Both are white, according to some authorities, but the smaller is sometimes said to be slightly greenish. Castor is an example of a Sirian star, such stars being dazzling white, often inclining towards a steely blue. The components of Castor can only be seen with a telescope, for the most powerful field-glass fails to separate them. When Castor is observed with an opera-glass, clusters and groups of stars, are seen in the near neighborhood, arranged in a most symmetrical way, as if with a definite plan, recalling the curving streams and wreaths of stars, in the regions of the Milky Way.

As a binary star, Castor excels; the two stars circling around one another during a period of about a thousand years, whilst it seems to have taken captive a tenth magnitude star which follows in its train at a distance of 74″, thus completing this unique system. Castor is receding from the Earth at the rate of 25 miles a second.

Pollux is one of the ten brightest stars north of the equator. Seen with a fine telescope, it presents the appearance of a triple star, whilst in larger instruments it is multiple. The components are orange, grey, and lilac, and if there are planets circling around this system, how strange must be the effect, when the colored suns shine upon these little worlds. Pollux is approaching the Earth with an average speed of somewhere about 40 miles a second.

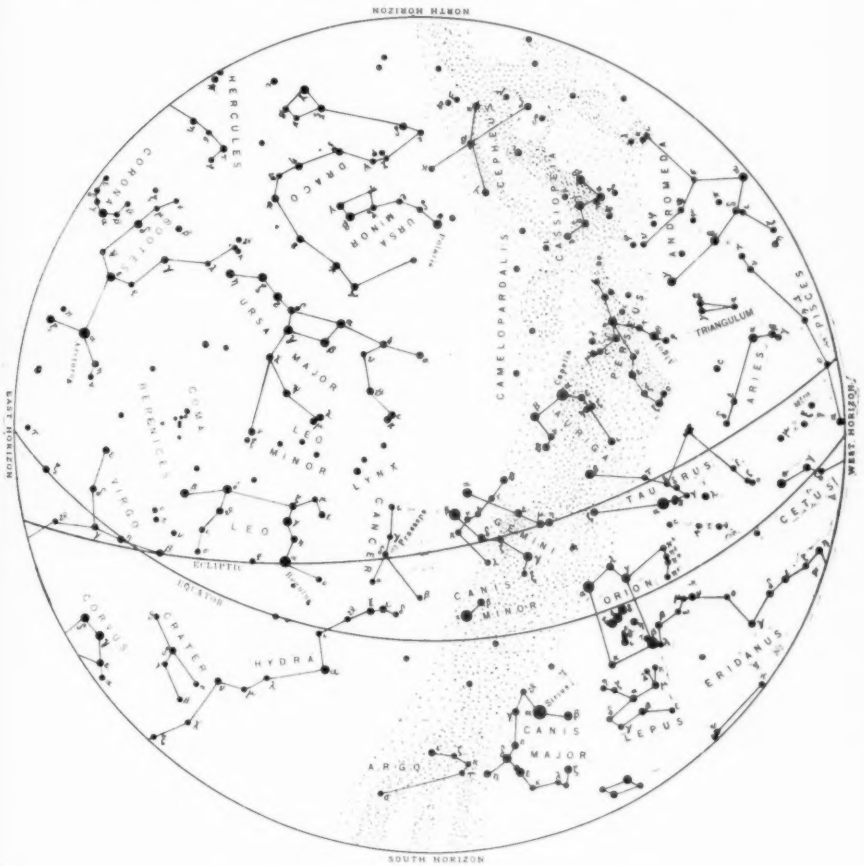
Other Fine Objects in Gemini.

There is a remarkable cluster of stars in Gemini (N.G.C. 2331) resembling a half opened fan, and composed of six or seven stars drawn closely together, as though by some irresistible power of attraction.

Zeta Geminorum, is a variable star referred to in S. C. Chandler's catalogue of 225 variables (*Astronomical Journal*, September, 1888) and its period is 10 days, 3 hours, 41 minutes and 30 seconds, its range of variation being from the 3.7 to the 4 5 magnitudes.

Eta Geminorum is another variable star referred to in this catalogue, its phases running through a period of 229 days, and varying between 3.2 and 4.2 magnitudes. In 1881, whilst Professor Burnham was observing this star through the great telescope at the Lick Observatory, he noticed that it was a variable double star, "a splendid unequal pair likely to prove an interesting system. Its revolutions deserve the more attention, as no star showing a banded spectrum has yet given signs of orbital movement." The spectrum of this star shows that it belongs to the third type, the orange stars, of which Alpha Orionis, and the variable star *Mira Ceti* are types. Variable stars of irregular period are included in this class. Their spectrum is characterized by dark bands, very dark towards the blue end shading off gradually towards the red end.

U Geminorum is an irregular variable star, being usually below the 14th magnitude, suddenly gaining in brightness until it exceeds the 9th magnitude. "When it was observed during the month of February, 1869, it increased sixteen fold in brightness during 24 hours, and its magnitude was estimated on February 20th at 13.2, but twenty-six hours later, at 9.8. According to certain ob-



THE CONSTELLATIONS AT 9 P. M. MARCH 1, 1897.

servations made by Mr. Knott, this star exhibited two types of maximum. In one, the entire swing to and fro, between the 14th and the 9th magnitudes, is completed in 10 days or even less. In the other it occupies from 15 to 20 days. A pause at the summit in the latter case, with a tendency to a secondary maximum, accounts for the difference. The light-curve takes more or less the form of a double peak with a saddle between. (Systems of the Stars, pp. 115-116).

The outbursts of U Geminorum are not wholly capricious. There is a certain disorderly order about them by which they somewhat resemble the changes of such stars as Mira. According to Mr. Lockyer's meteoric theory "variable stars are to be regarded as incipient double stars, they are actually meteoric swarms with double nuclei, one of which moves swiftly round the other, and at its nearest approach dashes right through its outlying portions with the result of innumerable collisions between individual meteorites, accompanied by a vast increase in the combined light of the swarm. But this state of things could not long subsist. By mechanical necessity the satellite swarm should speedily become extended into a ring with, of course, complete effacement of invariability. Thus each maximum of a star like Mira, if produced in the way supposed, would be feebler and more prolonged than its predecessor, until maxima and minima were brought to the same uniform level.,' (System of the Stars, p. 213).

R Geminorum is a star changing in 371 days from above the 7th to below the 12th magnitude. It might be called the comet-variable, since the three bright bands of carbon usually seen in comets, were most probably recorded in its spectrum by Vogel, as it rose towards a maximum on April 7th, 1874.

Cancer, the Crab.

Mythologists give the following account of this constellation. They say, that while Hercules was engaged in his fearful contest with the nine-headed Lernean hydra, Juno, envious of the fame of the hero's achievements, sent a sea-crab to bite his heel, but the crab being easily dispatched, the goddess, to reward its services, placed it among the constellations.

"The Scorpion's claws here clasp a wide extent,
And here the Crab's in lesser clasps are bent."

There are several double and nebulous stars in this constellation, the star Iota Cancri being a wide double, the colors of the components being orange and blue.

An Algol Variable.

S Cancri is an Algol variable, having a period of 9 days, 11 hours, 37 minutes and 45 seconds, according to the observations made by Hind, in 1848. The amount and duration of change, is from the 8.2 to 9.8 magnitudes, in 21 hours, 30 minutes. Stars of the Algol type, belong to Pickering's fifth class of variables, and their variability always consists in a temporary loss of light. They undergo, in fact, what are known to be real eclipses at stated intervals, while shining, for the most part, as steadily as ordinary stars.

An Anti-Copernican System.

Zeta Cancri is composed of three yellow stars. "This star," Sir John Herschel in 1826, "presents the hitherto unique combination of three individuals, forming, if not a system, connected by the agency of attractive forces, at least one in which all the parts are in a state of relative motion. Its perturbations, if really ternary, must present, one of the most intricate problems in physical astronomy." Miss Agnes Clerke gives a very interesting account of this triple system. The star *C* apparently retrogrades around *AB* at an average rate of half a degree a year, indicating (if maintained with approximate uniformity) a revolution in a period of 600 or 700 years. But this average rate is subject to very remarkable irregularities. The path traced out in the sky, far from being a smooth curve, is looped into a series of epicycles, in traversing which the star alternately quickens

and slackens, or even altogether desists from its advance, while increasing or diminishing, by proportionate amounts, its distance from the center of motion. From M. Seeliger's recent researches, the star C is merely a satellite to a dark body round which it describes, in 17½ years, a little ellipse, with a mean radius of one-fifth of a second. Together this singular pair circles, or is circled by *AB*, the invisible disturbing body being, quite possibly, the most massive of the system. An anti-Copernican system seems to be to some extent exemplified by Zeta Cancri. Here a cool, dark globe, clothed possibly with the vegetation appropriate to those strange climes, and plentifully stocked, it may be, with living things, is waited on, for the supply of their needs, by three vagrant suns, the motions of which it controls, while maintaining the dignity of its own comparative rest or rather of its lesser degree of movement. For the preponderance of this unseen body cannot approach that of a sun over its planets; hence its central position is by no means undisturbed. (System of the Stars, p. 210, 211).

THE PRAESEPE, OR MANGER.

In the center of the constellation Cancer, is the famous cluster of stars known as the Praesepe, or Manger. The opera glass shows it crowded with small stars, which are more distinct, when seen with a large field glass. This is a cluster that can be easily seen with the unaided eye, but only when the atmosphere is perfectly clear, otherwise it fades from sight. For this reason, it is looked upon by the mariner, as a sign of fair weather. Aratus bids us:

"Watch the Manger; like a little mist
Far north in Cancer's territory it floats.
Its confines are two faintly glimmering stars;
These are two asses that a manger parts,
Which suddenly, when all the sky is clear
Sometimes quite vanishes, and the two stars
Seem to have closer moved their sundered orbs.
No feeble tempest then will soak the leas;
A murky manger with both stars
Shining unaltered is a sign of rain."

"The two stars on either side of the manger are called the Aselli, or the Ass's Colts, and the imagination of the ancients, pictured them feeding from their silver manger." ("Astronomy with an Opera-Glass" p. 15.)

AURIGA, THE CHARIOTEER.

Auriga, the Charioteer, is represented on the celestial map, by the figure of a man, resting one foot upon the horn of Taurus, with a goat and her kids in his left hand, and a bridle in his right. It is situated north of Taurus and Orion.

Auriga is connected with the stars of Phæton, the son of Apollo, who borrowed the horses of his father and was overthrown in mid-heaven.

Capella and the kids were regarded by astrologers as of kindly influence, especially towards sailors.

The whole number of visible stars in Auriga, is 66, including one of the first and one of the second magnitude, which mark the shoulder. Capella is the principal star in this constellation, and is one of the most brilliant in the heavens. It takes its name from Capella, the goat, which hangs upon the left shoulder of Auriga.

CAPELLA.

Capella is one of the brightest stars in the northern heavens, and gleams with a creamy-white light. "Its constitution as revealed by the spectroscope, resembles that of our Sun, but the Sun would make but a sorry figure if removed to the

side of this giant star." About seven and a half degrees above Capella, and a little to the left, there is a second magnitude star called Menkaline. Two and a half times as far to the left, or south, in the direction of Orion, is another star of equal brightness to Menkalina. This is El Nath, and marks the place where the foot of Auriga, or the Charioteer rests upon the horn of Taurus. Capella, Menkalina, and El Nath make a long triangle which covers the central part of Auriga. The naked eye shows two or three misty-looking spots within this triangle, one to the right of El Nath, one in the upper or eastern part of the constellation, near the third magnitude star Theta, and another on a line drawn from Capella to El Nath, but much nearer to Capella. Turn your glass upon these spots, and you will be delighted by the beauty of the little stars to whose united rays they are due. El Nath has around it some very remarkable rows of small stars, and the whole constellation of Auriga like that of Gemini, glitters with star dust, for the Milky Way runs directly through it. With a powerful field glass, you may get a glimpse of the star-clusters 38 M, 37 M, and 33." (Astronomy with an opera-glass, p. 22)

BETA AURIGÆ.

From observations made of the spectrum of Beta Auriga, the doubling of the spectral lines every alternate night, implies orbital revolution in a period of four days. The explanation of this, is given as follows, by Professor Newcomb, in his *Popular Astronomy*: "We have here a double star, each component of which sends out its own rays. The two stars are revolving round each other. When they are nearly in the same line from the Earth, the lines formed by the light from the two stars coalesce, and seem as a single line, but when one star is moving from the Earth, and the other moving to it, the lines produced by one are displaced towards the red end of the spectrum, and those produced by the other towards the blue end. Thus they are separated so as to form a double line. Spectroscopic examination is bringing to light dark planets moving around the fixed stars, the detection of which would have been forever hopeless by direct telescopic research." (POPULAR ASTRONOMY, p. 471).

N. B —Please note that in the December number of POPULAR ASTRONOMY page 324, line 5, Alpha *Centauri* should read Alpha *Cygnus*. MARY PROCTOR

PLANET NOTES FOR MARCH.

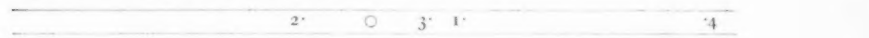
H. C. WILSON.

Mercury is passing around behind the Sun and will reach superior conjunction April 1.

Venus is still increasing in brilliancy and will reach her maximum March 21. She has already begun to turn in between the Earth and Sun and will rapidly lose the favorable position for observation which she now occupies. Venus will be in perihelion March 4 and in conjunction with the Moon March 7.

Mars will be in conjunction with the Moon March 11 at 5:51 P. M., Central time and at quadrature, 90° east from the Sun, March 18. This planet is still in good position for study being only a little way west of the meridian at 7 P. M., and at a high altitude. The diameter of the disk is, however, getting small, being now 9″ and at the end of the month only 7″. The minute markings on the disk will therefore be seen with difficulty. Mars is between the horns of Taurus and is moving eastward across the Milky Way.

Jupiter is now seen toward the east in the early evening, among the stars of the constellation Leo, and will be an interesting object to study during the next three or four months. We give among the tables diagrams showing the relative positions of the satellites for each day of the month at $10^h\ 30^m$ P. M. Central standard time. In these diagrams the numerals 1, 2, 3 and 4 represent the four satellites in the order of their distance from the planet. The dot beside each numeral represents the position of the satellite. The figure is placed on the side of the dot toward which the satellite is moving. A glance thus shows not only the relative positions of the satellites but the direction of their apparent motions. Thus for March 1 the diagram is as follows:



Satellite II is at the left of the planet and moving toward the left. Satellites III and I are on the right of the planet but are moving toward the left, while Satellite IV is moving toward the right.

In the table of Phenomena of Jupiter's satellites are given the approximate Central standard times of the beginning and ending of the kinds of phenomena exhibited by the satellites, viz., Tr. transit of the satellite across the disk of the planet, Sh. transit of the shadow of the satellite, Oc. occultation of the satellite by the body of the planet, and Ec. eclipse of the satellite in the shadow of the planet. There are so many of these phenomena that it is necessary to abbreviate their designation as much as possible, but a very little study will enable the reader to use the table without difficulty.

For example, on March 5 we find the phenomena predicted as follows:

3	58 P. M.	III	Oc. Dis.
6	17 "	I*	Tr. In.
6	32 "	I*	Sh. In.
8	27 "	III*	Ec. Re.
8	36 "	I*	Tr. Eg.
8	51 "	I*	Sh. Eg.

which, being interpreted, means that at $3^h\ 58^m$ P. M. the third satellite will disappear by occultation behind the planet; at $6^h\ 17^m$ P. M. the first satellite will begin transit across the disk of the planet; its shadow will follow in transit as a black round spot fifteen minutes later, and both will be in transit together for over two hours, passing off the disk at $8^h\ 36^m$ and $8^h\ 51^m$ respectively. At $8^h\ 27^m$ the third satellite will reappear from eclipse by the shadow of the planet, having entered the shadow before emerging from occultation.

Saturn is visible toward the south at five o'clock in the morning, in the constellation Scorpio. He is almost stationary in right ascension during the month, turning back for a few months of retrograde motion.

Uranus is also in Scorpio, about 2° southwest from Saturn, but is not visible to the naked eye.

Neptune is in Taurus, visible in the early evening with a good telescope. Its position for March 15 is right ascension $5^h\ 6^m\ 30^s$, declination north 21° 30′, and changes very slowly.

The Moon.

	Phases.	Rises. (Local Time.)		Sets.	
		h	m	h	m
Mar. 3	New Moon	6	27 A. M.	6	24 P. M.
11	First Quarter	10	1 "	2	44 A. M.
18	Full Moon	6	24 P. M.	6	4 "
25	Last Quarter	2	4 A. M.	10	22 "

Jupiter's Satellites for March.

Central Standard Time.

Phases of the Eclipses of the Satellites for an Inverting Telescope.

I.

III.

II.

IV.

Configurations 10h 30m for an Inverting Telescope.

Day.	West.	East.
1	2· ○ 3· 1·	·4
2	3· ·2 ·1 ○	4·
3	3· ○ 1· ·2 4·	
4	·3 ○ 2· 4·	·1●
5	2· 1· ○ 4··3	
6	4· ○ ·1 ·3	·2●
7	4· 1· ○ 2· 3·	
8	4· 2· ○ 3· 1·	
9	4· 3 ·2 ·1 ○	
10	·4 3· ○ 1· ·2	
11	·4 ·3 ○ 2·	·1●
12	·4 2· 1· ○	·3●
13	·4 ·2 ○ ·1 ·3	
14	1· ○ ·4 ·2 3·	
15	2· ○ ·1 3 ·4	
16	·2 3· ·1 ○ ·4	
17	3· ○ 1··2	·4
18	·3 ·1 ○ 2·	4·
19	○1· 2· ○ 4·	·3●
20	·2 ○ ·1 ·3 4·	
21	1· ○ 4· ·2 3·	
22	○2· 4· ○ ·1 3·	
23	4· ·2 ·13· ○	
24	4· 3· ○ ·21·	
25	4· ·3 ○ 2·	
26	4· 2· ·3 ○ 1·	
27	·4 ·2 ○ ·3	·1●
28	·4 1· ○ ·2 3·	
29	·4 ○ 2· ·1 3·	
30	·2 1· 3· ·4○	
31	3· ○ ·2 1· ·4	

Phenomena of Jupiter's Satellites

[In. denotes ingress; Eg., egress; Dis., disappearance; Re., reappearance; Ec., eclipse; Oc., occultation; Tr., transit of satellite; Sh., transit of shadow; * visible at Washington.]

Central Standard Time.

		h	m			
March	1	1	54	P. M.	II	Tr In.
		2	12	"	II	Sh. In.
		4	45	"	II	Tr. Eg.
		5	5	"	II	Sh. Eg.
	2	2	23	A. M.	III	*Tr. In.
		3	1	"	III	*Sh. In.
		5	25	"	I	Tr. In.
		5	35	"	I	Sh. In.
		5	53	"	III	Tr. Eg.
		6	35	"	III	Sh. Eg.
		7	44	"	I	Tr. Eg.
		7	54	"	I	Sh. Eg.
	3	2	32	"	I	*Oc. Dis.
		5	0	"	I	*Ec. Re.
		8	53	"	II	Oc. Dis.
		12	7	P. M.	II	Ec. Re.
		11	51	"	I	*Tr. In.
	4	12	3	A. M.	I	*Sh. In.
		2	10	"	I	*Tr. Eg.
		2	22	"	I	*Sh. Eg.
		8	58	P. M.	I	*Oc. Dis.
		11	29	"	I	*Ec. Re.
	5	3	1	A. M.	II	*Tr. In.
		3	30	"	II	*Sh. In.
		5	53	"	II	Tr. Eg.
		6	23	"	II	Sh. Eg.
		3	58	P. M	III	Oc Dis.
		6	17	"	I	*Tr. In.
		6	32	"	I	*Sh. In.
		8	27	"	III	*Ec. Re.
		8	35	"	I	*Tr Eg.
		8	51	"	I	*Sh. Eg.
	6	1	14	A. M.	IV	*Tr. In.
		3	37	"	IV	*Sh. In.
		5	23	"	IV	Tr. Eg.
		8	9	"	IV	Sh. Eg.
		3	24	P. M.	I	Oc. Dis.
		5	58	"	I	*Ec. Re.
		10	1	"	II	*Oc Dis.
	7	1	25	A. M.	II	*Ec Re.
		12	43	P. M.	I	Tr. In.
		1	0	"	I	Sh In.
		3	2	"	I	Tr. Eg.
		3	20	"	I	Sh Eg.
	8	9	50	A. M.	I	Oc. Dis.
		12	26	P. M.	I	Ec. Re.
		4	8	"	II	Tr. In.
		4	47	"	II	Sh. In.
		7	0	"	II	*Tr. Eg.
		7	39	"	II	*Sh. Eg.
	9	5	40	A. M.	III	Tr. In.
		7	0	"	III	Sh. In.
		7	9	"	I	Tr. In.
		7	29	"	I	Sh. In.
		9	11	"	III	Tr. Eg.
		9	28	"	I	Tr. Eg.
		9	48	"	I	Sh. Eg.
		10	34	"	III	Sh. Eg.
	10	4	16	"	I	*Oc. Dis.
		6	55	"	I	Ec. Re.
		11	59	"	II	Oc. Dis.
		2	43	P. M.	II	Ec. Re.
	11	1	35	A. M.	I	*Tr. In.
		1	58	"	I	*Sh. In.
		3	54	"	I	*Tr. Eg.
		4	17	"	I	*Sh. Eg.
		10	42	P. M.	I	*Oc. Dis.
	12	1	23	A. M.	I	*Ec. Re.
		5	15	"	II	Tr. In.
		6	5	"	II	Sh. In.
		8	7	"	II	Tr. Eg.
		8	56	"	II	Sh. Eg.
		7	15	P. M.	III	*Oc. Dis.
		8	1	"	I	*Tr. In.
		8	26	"	I	*Sh. In.
		10	20	"	I	*Tr. Eg.
		10	45	"	I	*Sh. Eg.
	13	12	25	A. M.	III	*Ec. Re.
		5	8	P. M.	I	Oc. Dis.
		7	52	"	I	*Ec. Re.
	14	12	17	A. M.	II	*Oc. Dis.
		4	0	"	II	*Ec. Re.
		9	46	"	IV	Oc. Dis.
		2	8	"	IV	Oc. Re.
		2	11	"	IV	Ec. Dis.
		2	27	"	I	Tr. In.
		2	55	"	I	Sh. In.
		4	46	"	I	Tr. Eg.
		5	14	"	I	Sh. Eg.
		6	28	"	IV	*Ec. Re.
	15	11	35	A. M.	I	Oc. Dis.
		2	20	P. M.	I	Ec. Re.
		6	23	"	II	*Tr. In.
		7	22	"	II	*Sh. In.
		9	15	"	II	*Tr. Eg.
		10	14	"	II	*Sh. Eg.
	16	8	54	A. M.	I	Tr. In.
		8	59	"	III	Tr. In.
		9	24	"	I	Sh. In.
		11	0	"	III	Sh. In.
		11	13	"	I	Tr. Eg.
		11	43	"	I	Sh. Eg.
		12	30	P. M.	III	Tr. Eg.
		2	33	"	III	Sh. Eg.
	17	6	1	A. M	I	Oc. Dis.
		8	49	"	I	Ec. Re.
		1	26	P. M.	II	Oc. Dis.
		5	19	"	II	Ec. Re.
	18	3	20	A. M.	I	*Tr. In.
		3	52	"	I	*Sh. In.
		5	39	"	I	Tr. Eg.
		6	11	"	I	Sh. Eg.
	19	12	27	"	I	Oc. Dis.
		3	17	"	I	*Ec. Re.
		7	31	"	II	Tr. In.
		8	40	"	II	Sh. In.

	h	m			
March 19	10	23	"	II	Tr. Eg.
	11	32	"	II	Sh. Eg.
	9	44	P. M.	I	*Tr. In.
	10	21	"	I	*Sh. In.
	10	35	"	III	*Oc. Dis.
20	12	5	A. M.	I	*Tr. Eg.
	12	39	"	I	*Sh. Eg.
	4	24	"	III	Ec. Re.
	6	54	P. M.	I	*Oc. Dis.
	9	46	"	I	*Ec. Re.
21	2	34	A. M.	II	*Oc. Dis.
	6	35	"	II	Ec. Re.
	4	13	P. M.	I	Tr. In.
	4	50	"	I	Sh. In.
	6	32	"	I	*Tr. Eg.
	7	9	"	I	*Sh. Eg.
22	1	20	"	I	Oc. Dis.
	3	39	"	IV	Tr. In.
	4	15	"	I	Ec. Re.
	8	4	"	IV	*Tr. Eg.
	8	40	"	II	*Tr. In.
	9	37	"	IV	*Sh. In.
	9	58	"	II	*Sh. In.
	11	32	"	II	*Tr. Eg.
23	12	50	A. M.	II	*Sh. Eg.
	2	5	"	IV	*Sh. Eg.
	10	39	"	I	Tr. In.
	11	18	"	I	Sh. In.
	12	20	P. M.	III	Tr. In.
	12	58	"	I	Tr. Eg.
	1	37	"	I	Sh. Eg.
	2	58	"	III	Sh. In.
	3	52	"	III	Tr. Eg.
	6	31	"	III	*Sh. Eg.
24	7	45	A. M.	I	Oc. Dis.
	10	43	"	I	Ec. Re.
	3	44	P. M.	II	Oc. Dis.
	7	55	"	II	*Ec. Re.
25	5	6	A. M.	I	Tr. In.
	5	47	"	I	Sh. In.
	7	25	"	I	Tr. Eg.
	8	6	"	I	Sh. Eg.
26	2	13	"	I	*Oc. Dis.
	5	12	"	I	Ec. Re.
	9	49	"	II	Tr. In.
	11	15	"	II	Sh. In.
	12	41	P. M.	II	Tr. Eg.
	2	7	"	II	Sh. Eg.
	11	32	"	I	*Tr. In.
27	12	16	A. M.	I	*Sh. In.
	1	51	"	I	*Tr. Eg.
	1	59	"	III	*Oc. Dis.
	2	35	"	I	*Sh. Eg.
	8	23	"	III	Ec. Re.
	8	39	P. M.	I	*Oc. Dis.
	11	41	"	I	*Ec. Re.
28	4	53	A. M.	II	Oc. Dis.
	9	13	"	II	Ec. Re.
	5	59	P. M.	I	*Tr. In.
	6	44	"	I	*Sh. In.
	8	18	"	I	*Tr. Eg.
	9	3	"	I	*Sh. Eg.
29	3	6	"	I	Oc. Dis.
	6	9	"	I	*Ec. Re.
	10	58	"	II	*Tr. In.
30	12	33	A. M.	II	*Sh. In.
	1	50	"	II	*Tr. Eg.
	3	24	"	II	Sh. Eg.
	12	25	P. M.	I	Tr. In.
	1	13	"	I	Sh. In.
	2	44	"	I	Tr. Eg.
	3	32	"	I	Sh. Eg.
	3	44	"	III	Tr. In.
	6	57	"	III	*Sh. In.
	7	17	"	III	*Tr. Eg.
	10	29	"	III	*Sh. Eg.
31	12	27	A. M.	IV	*Oc. Dis.
	4	55	"	IV	Oc. Re.
	8	12	"	IV	Ec. Dis.
	9	33	"	I	Oc. Dis.
	12	25	P. M.	IV	Ec. Re.
	12	38	"	I	Ec. Re.
	6	4	"	II	*Oc. Dis.
	10	31	"	II	*Ec. Re.
April 1	6	52	A. M.	I	Tr. In.
	7	42	"	I	Sh. In.
	9	11	"	I	Tr. Eg.
	10	1	"	I	Sh. Eg.

Occultations Visible at Washington.

Date 1897.	Star's Name.	Magnitude.	IMMERSION. Washington M. T. h	m	Angle from N pt. °	EMERSION. Washington M. T. h	m	Angle from N pt. °	Duration. h	m
Mar. 14	35 Cancri	6 3	8	15	38	8	28	19	0	13
14	δ Cancri	4.0	13	55	82	14	42	332	0	47
15	18 Leonis*	6.0	18	1	79	18	39	327	0	38
15	19 Leonis*	7.0	18	25	107	19	10	298	0	45
22	π Scorpii	3.4	8	25	185	8	35	208	0	10
22	B.A.C 5347	6.0	11	27	72	12	17	328	0	50
23	43 Ophiuchi	5.8	16	59	71	18	18	289	1	19
25	ψ Sagittarii*	5.4	11	51	51	12	34	304	0	43
26	4 Capricorni†	6.1	14	31	88	15	37	248	1	6
29	67 Aquarii*	6.4	14	37	142	14	52	175	0	15
30	12 Piscium*	6.8	15	36	113	16	12	197	0	36
31	22 Piscium*	5.0	7	14	11	7	41	305	0	27

* Whole occultation below the horizon at Washington. † Immersion below the horizon at Washington.

Ephemeris for Physical Observations of Mars.

(From *Monthly Notices, R. A. S.*, April, 1897.]

Greenwich Noon.		Position Angle of Axis. °	Areographic Latitude Center of Disk. °	Areographic Longitude Centre of Disk. °	Passage of Zero Meridian. (Cen. St'd Time.) h	m	
Mar.	2	329.57	− 2.32	40.50	3	14	A. M.
	4	329.92	1.95	21.56	4	31	"
	6	330.28	1.57	2.60	5	49	"
	8	330.66	1.18	343.63	7	7	"
	10	331.05	0.78	324.64	8	25	"
	12	331.45	− 0.37	305.63	9	43	"
	14	331.86	+ 0.04	286.61	11	2	"
	16	332.29	0.45	267.58	12	20	P. M.
	18	332.73	0.87	248.54	1	38	"
	20	333.18	1.30	228.48	2	56	"
	22	333.64	1.73	210.42	4	15	"
	24	334.12	2.17	191.34	5	33	"
	26	334.61	2.61	172.25	6	51	"
	28	335.10	3.05	153.15	8	10	"
	30	335.61	+ 3.50	134.04	9	28	"

Ephemeris for Physical Observations of Jupiter.

(From *Monthly Notices, R. A. S.*, Vol. LVI, No. 10.)

Greenwich Noon.		Position Angle of Axis. °	Latitude of Centre of Disk. °	Longitude of Centre of Disk. °	Passage of Zero Meridian. Central Standard Time. h	m	
Mar.	2	23.60	− 1.26	132.72	10	12	P. M.
	4	23.56	1.25	73.49	11	50	"
	6	23.52	1.24	14.25	3	32	"
	8	23.48	1.23	315.00	5	10	"
	10	23.44	1.22	255.74	6	48	"
	12	23.40	1.21	196.48	8	26	"
	14	23.36	1.20	137.20	10	4	"
	16	23.32	1.19	77.90	11	42	"
	18	23.28	1.18	18.59	3	25	"
	20	23.24	1.17	319.27	5	3	"
	22	23.21	1.16	259.94	6	41	"
	24	23.17	1.16	200.59	8	20	"
	26	23.14	1.15	141.22	9	58	"
	28	23.11	1.14	81.85	11	36	"
	30	23.08	− 1.13	22.46	3	19	"

Average daily change of longitude of centre of disk + 870°.27; hourly change + 36°.26. Average interval between successive passages of zero meridian $9^h\ 55^m.7$.

COMET NOTES.

Elliptic Elements and Ephemeris of Comet *g* 1896 (Perrine).—The following system of elements is based upon normal places from observations on Dec. 8, 9, 10 (Mt. Hamilton), Dec. 10 (Munich, Bamberg, Strassburg, Nice), Dec. 11 (Vassar, Edinburg). Jan. 2 (Bamberg, Strassburg), Jan. 4, 5, 6, 8 (Mt. Hamilton), Jan. 20, 21, 22, 23, 24, 25 (Mt. Hamilton).

EPOCH 1896, DEC. 10.0 GR. M. T.

	°	′	″	
M	2	22	49.6	
ω	163	52	8.7	1897.0
Ω	246	36	4.4	
i	13	39	24.5	
log a	0.536366			
log e	9.830734			
log μ	2.745458			
φ	21°	18′	49″.0	
Period	6.376 years.			

CONSTANTS FOR THE EQUATOR OF 1897.0.

$x = r\,[9.989557]\,\sin\,(139°\ 51'\ 56''.0)$
$y = r\,[9.979418]\,\sin\,(\ 45\ \ 51\ \ 7\ .9)$
$z = r\,[9.568973]\,\sin\,(\ 83\ \ 39\ \ 27\ .5)$

EPHEMERIS FOR GREENWICH MEAN MIDNIGHT.

1897.		α h	m	s	δ °	′	″	log r	log Δ	Br.
Feb.	20.5	5	56	59.0	+ 2	23	55	0.1974	9.9451	0.046
	22.5	6	1	23.8	2	35	51			
	24.5	6	5	45.0	2	47	34	0.2064	9.9716	0.039
	26.5	6	10	3.0	2	59	00			
	28.5	6	14	18.0	3	10	8	0.2154	9.9973	0.033
March	2.5	6	18	30.4	3	20	56			
	4.5	6	22	40.3	3	31	21	0.2242	0.0224	0.028
	6.5	6	26	47.9	3	41	23			
	8.5	6	30	53.4	3	51	00	0.2328	0.0467	0.024
	10.5	6	34	57.0	4	00	11			
	12.5	6	38	58.6	4	8	56	0.2414	0.0703	0.021
	14.5	6	42	58.2	4	17	14			
	16.5	6	46	56.0	4	25	4	0.2498	0.0932	0.018
	18.5	6	50	52.2	4	32	26			
	20.5	6	54	46.7	4	39	20	0.2580	0.1154	0.016
	22.5	6	58	39.7	4	45	46			
	24.5	7	2	31.2	4	51	44	0.2661	0.1370	0.014
	26.5	7	6	21.3	4	57	12			
	28.5	7	10	10.1	5	2	11	0.2741	0.1580	0.012
	30.5	7	13	57.6	5	6	42			
April	1.5	7	17	44.0	5	10	44	0.2819	0.1784	0.011
	3.5	7	21	29.2	5	14	16			
	5.5	7	25	13.3	5	17	19	0.2896	0.1981	0.009
	7.5	7	28	56.2	5	19	53			
	9.5	7	32	38.1	+ 5	21	57	0.2971	0.2173	0.008

Brightness on Dec. 8 unity.

C. D. PERRINE AND R. G. AITKEN.

Lick Observatory, University of California,
February 8, 1897.

VARIABLE STARS.

I. A. PARKHURST.

Maxima and Minima of Long Period Variables.

1897 May.

MAXIMA.

	Day
62 S Sculptoris	11:
401 U "	15:
845 R Ceti	5
1222 R Persei	8
1717 V Tauri	20
2528 R Geminorum	28
3994 S Leonis	17
4260 W Centauri	26:
4511 T Ursæ Maj.	29
4521 R Virginis	22
5511 RS Libræ	18
5583 X Libræ	9
5675 V Coronæ	8
5758 X Herculis	6
5831 S Scorpii	28
6449 T Draconis	15

MAXIMA, CON'T.

	Day
6608 RV Sagittarii	14
7106 S Vulpeculæ	7
7192 Z Cygni	7
7220 S Cygni	3
7404 R Microscopii	21
7444 T Delphini	11
7456 RR Cygni	21:
7571 V Capricorni	6
7909 S Piscis Aust.	23

MINIMA.

107 T Cassiopeæ	20
432 S Cassiopeæ	9:
715 S Arietis	7:
1805 V Orionis	7
2676 U Monocerotis	17

MINIMA CONT.

	Day
3493 R Leonis	17
3637 S Carinæ	10
4492 Y Virginis	1:
4557 S Ursæ Maj.	4
4596 U Virginis	30
5190 R Camelopard.	15:
5338 U Boötis	7
5889 U Herculis	8
6794 R Lyræ	18
6921 S Sagittarii	14:
7085 RT Cygni	12
7242 S Aquilæ	25
7609 T Cephei	15
7659 T Capricorni	28
8324 V Cassiopeæ	20
8591 V Cephei	21

Minima of the Variable Stars of the Algol Type.

[Given to the nearest hour in Greenwich Mean Time.]

U CEPHEI.

1897.	d	h
Apr.	2	18
	7	18
	12	18
	17	17
	22	17
	27	17

ALGOL.

Apr.	2	21
	8	15
	28	17

R CANIS MAJ.

Apr.	8	8
	10	15
	16	7
	18	14

S CANCRI.

Apr.	17	11

S VELORUM.

1897.	d	h
Apr.	3	9
	9	8

δ LIBRAE.

Apr.	2	18
	7	9
	9	17
	14	9
	16	17
	21	8
	23	16
	28	8
	30	16

U CORONAE.

Apr.	5	15
	12	13
	19	11
	22	22
	29	19

RS SAGITTARII.

1897.	d	h
Apr.	5	14
	12	20
	17	16
	22	12
	24	22
	29	17

U OPHIUCHI.

Apr.	2	21
	3	17
	4	13
	5	9
	7	21
	8	18
	9	14
	10	10
	12	22

U OPHIUCHI Con.

1897.	d	h
	13	18
	14	14
	15	11
	17	23
	18	19
	19	15
	20	11
	23	20
	24	16
	25	12
	28	21
	29	17
	30	13

W DELPHINI.

Apr.	15	19
	20	14

The above ephemeris is computed for POPULAR ASTRONOMY directly from the elements given in Chandler's Third Catalogue. For the Algol type stars I have given all the minima which occur in the night hours in American and European longitudes, when the star is above the horizon. In the long period ephemeris all the stars are given whose periods are greater than 40 days.

678 U Persei. The data for the minimum of this star are not given in the Third Catalogue, but in the ephemeris for 1897, in *Astronomical Journal*, No. 387, the minimum is predicted for May 2, corresponding to $M - m = 168$ days.

Anderson's new variable in Herculis, charted in POPULAR ASTRONOMY for January, page 384, has received the designation 5798 RU Herculis. It proves to have considerable range, as it was found as bright as the 7th magnitude by Hartwig in November, 1896. On Jan. 7, 1897 I found it had fallen again to the 9th magnitude.

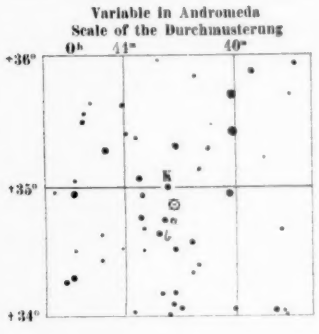
In *Astronomische Nachrichten* No. 3394 Anderson announces the discovery of a new variable in Andromeda. He found it 8.5 mag. early in November, 1896, and 9.4 mag. December 24. I found it 11.6 mag., 1897, January 19, and 12.3 mag., January 30. I have measured its position with reference to the nearest catalogue star and find:

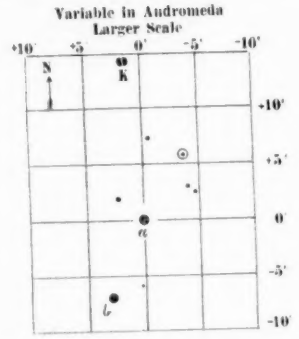
R. A.	$0^h\ 42^m\ 13^s.2$,	Decl.	$+34°\ 51'\ 46''$, 1855
	$44\ \ 39\ .4$		$35\ \ 6\ \ 32$ 1900

The three nearest comparison stars with their approximate magnitudes and coordinates from the variable are:

	Mag.	R. A.	Decl.
d	12.5	$+3'$	$+1'$
g	12.2	0	-3
h	12.4	-1	-4

The accompanying chart on the scale of the Durchmusterung will serve to identify the field, but since the variable is now faint the larger scale chart will be needed also. The comparison star *k* lettered on each chart is a neat low power double, with components about equal.





The new Wells' variable in Cygnus, charted in the February POPULAR ASTRONOMY, page 446, has received the designation 7792 SS Cygni. As suspected in the previous note it seems to be of the "U Geminorum" type, remaining most of the time about the 11th magnitude, rising suddenly to its maximum, 7.0 — 8.5 mag., and falling more slowly to 11. I found a maximum about 1897, Jan. 17, at 8.5 mag., with the time of rise not greater than 8 days and the time of fall not less than 16 days. As this star and U Geminorum are the only known examples of this remarkable type they deserve the most careful watch. Mr. Yendell's determination of this maximum will be published in the *Astronomical Journal* before this note appears.

GENERAL NOTES.

We have again added several pages to the usual size of our monthly issue, to get space for Dr. Morrison's excellent article on the computation of Solar Eclipses. It will be difficult reading for some of our patrons, but these will please remember that this matter is exactly what has been asked for by others, and that it is greatly appreciated by still others.

The April number of this publication will close its fourth volume. In view of this fact, we especially ask our many friends whose subscriptions then expire to favor us with prompt renewals, and to further aid us by calling the attention of acquaintances and friends interested in such a magazine to lend their support also to it. If the subscription list were double its present size, we would at once double the size of every regular issue.

Professor Barnard has been giving recently a series of astronomical lectures in the east, at Vassar College, Columbia College and the Academy of Science and Art, Pittsburg. These lectures were illustrated by a large number of slides made from Professor Barnard's famous celestial photographs.

Fine Daylight Meteor.—A beautiful daylight meteor was seen by the writer on the afternoon of January 19, soon after sunset. Its brilliance exceeded that of Venus at this time, and the meteor moved slowly southward across the eastern sky. The visible flight was nearly thirty degrees in length, ending at an altitude of fifteen degrees above the horizon. WILLIAM R. BROOKS.

Smith Observatory, Geneva, N. Y., Jan. 25th, 1897.

Solutions of Problems in December Number.—Mr. Thomas Lindsay of Toronto, Ont., solved problems 22, 23 in part, 24, 25 and 26 in part.

Mr. Orrin E. Harmon, Chehalis, Wash., solved problems 22 and 23 in part, and 24, 25 and 26.

January Chronological Notes.—The threshing of "old straw" is not usually a lucrative employment—still sometimes a grain or two may be had by the operation.

I have seen only the first edition of Young's Astronomy. My purse is not sufficiently plethoric to allow me to indulge in the luxury of other editions—even of books which I should like to own, and this Astronomy is of the desirable kind. The slight errors pointed out, one will remember were likened to spots on the Sun which do no harm, but still are *spots*.

The first edition from which I quoted has, on p. 145, an article numbered 229; and the article is headed "Sidereal and Synodic Revolutions." On the same page is article 231 headed "Determination of Synodic Period." The word "Sidereal" does not occur anywhere in this article. These facts constitute one reason why I supposed the synodic period was the one under discussion. A second reason was that the revolution of the Moon from eclipse to eclipse necessarily implies the "synodic" period, not the "sidereal." For these reasons I said that there was an error of more than 2000 revolutions. These points do not admit of discussion,—unless discussion may be had where there is only one side to a case.

Professor Young says, "On another point I must join issue with my critic:—his statement that the "days" vary in length to an appreciable amount." This expression is not in my article at all, nor is the idea there. The paragraph on p. 354 of my January article limits the word "day" to the revolution of the Earth on its axis from meridian to meridian; and it is expressly stated that "this unequal motion of the Earth in its orbit is one of the two causes which make the Sun and the clock differ in the hour of noon." The other cause was purposely omitted, for I was not explaining the "Equation of Time." Again; on p. 355 I say "From the preceding statements it appears that the difference between the longest day and the shortest one is about one fourth of a minute." I thus distinctly limited the term day to the kind of revolution there mentioned. And the difference so given is absolutely correct, and is not subject to exceptions or objections The second cause varies in its amount with the inclination of the Earth's axis to the plane of its orbit: and is a little greater than the amount arising from the first cause. It perhaps would have been better to have given a full explanation of both causes; but I strove to make the article as brief as would be consistent with clearness, and many extracts originally intended for the article were entirely omitted.

Further, as to the various meanings of the word "day" in scientific treatises,—I purposely omitted any reference to unscientific uses of the word,—we have the original "sidereal" day—the revolution from star back to the same star—a term long since laid aside from general scientific use: then we have the "mean equinox" and the "true equinox;" and consequently, we have the "mean sidereal" day, and the "true sidereal" day: we have also the "solar day" and the "mean solar" day, etc., etc., but of all these I said not a word. I was not explaining the term "day," with all its wealth of adjectives.

A critical reading of these parts of my January article will show that the points of objection are not well taken, although they are such as might occur on a cursory reading.

Every fact and every sentence in that article was subjected to repeated critical examination, before the article was sent in: and I thought then and think now that the facts brought out can not be disputed by any one familiar with the subject in all its ramifications. R. W. McFarland.

Ohio, Feb. 10, 1897.

U Geminorum.—The attention of observers of variable stars is called to the desirability of securing a continuous series of observed dates of the maxima of this star, in order that it may be possible to determine the law of its irregularities. These are so great that the occurrence of a gap of three epochs in the series of observed dates renders the whole number of periods uncertain. There now exists several such gaps, so that though the periodical character of the irregularities seem certain, its value cannot be certainly determined. It is therefore very much desired that a continuous series of maxima may be observed. Owing to the peculiar character of the star's variation, the only way to do this is by looking at the star on each night when observing. In order to secure the desired result, I will furnish any one who wishes for them, all necessary data for identification, with chart and list of comparison-stars. Correspondence is invited.

19 Winter St., Dorchester, Mass., 1897, Feb. 3. P. S. YENDELL.

Venus.—I suppose all the readers of POPULAR ASTRONOMY know the size of Venus, the time of her revolution around the Sun, her axiel revolution, her distance from the Sun and Earth, her telescopic appearance; showing her different phases in her orbit around the Sun, etc. It will be profitable to all who take an interest in the movements of the heavenly bodies to observe Venus for the next two or three months in her westward movement towards the Sun. On the 16th of February she was at her greatest elongation east of the Sun. She is now returning towards the Sun and is still increasing in brilliancy till about the 20th of March she will be bright enough to cast a shadow, at night, and can easily be seen with the naked eye in day time providing one knows just where to look for her She will continue her course toward the west, and every evening we find her a little nearer the Sun, and decreasing in brilliancy, and finally disappearing in the bright rays of the Sun, and setting when ths Sun sets. This will occur April 29th when she will be in her "inferior conjunction" and Venus will pass from evening to morning star, and cannot be seen for about one week or ten days. After this Venus will rise before Sun and adorn the eastern sky before daylight the same as she now appears in the western sky. Venus will be in her greatest beauty as morning star the first and second week in June. It will pay any one to rise before daylight and see Venus in her greatest brilliancy as a morning star.

MARTIN WINGER.

The Astronomical and Physical Society of Toronto.—The opening meeting for 1897 was held Jan. 19th, when the president, Mr. John A. Paterson, M. A., read an exhaustive review of the progress of astronomy during 1896, and of the society's own special work. The most important work now being undertaken is perhaps the earth-current investigations, but several of the members have been interested in sketching the lunar surface and the appearance of the solar disc on all possible occasions. This work, being admirably suitable for amateurs, it was hoped would be continued. It was announced that one of the lady members would at the next meeting present a review of the articles on Venus and Mercury which recently appeared in the pages of POPULAR ASTRONOMY. The society lost two of its members by death, during the year, Mr. John Goldie, of Galt and Dr. J. C. Donaldson, of Fergus, Ont.

At the meeting held Feb. 2d, Miss A. A. Gray read the text of the report from Percival Lowell's Observatory on the planet Mercury and reproduced on the blackboard the drawings which appeared in POPULAR ASTRONOMY. An interesting discussion followed. Mr. Harvey pointed out, that, while only a part of the planet's surface was visible to an observer on the Sun, if there were no axial rotation of short period, all parts of the disc must be presented in turn to the Earth. He would await further observations of the markings on the other side. Mr. Lindsay recalled an essay by the late Professor Coakley published in the *Sidereal Messenger*, in which it was shown that it is very unlikely that the planet keeps one face to the Sun. In illustrating the analysis given by Coakley, Mr. Lindsay stated that in view of the many vicissitudes in the life history of a planet it was difficult to see how it could ever avoid the rotational movement, unless tidal, action, as in the case of the Moon, stopped it; and it had been shown that the power of the Sun upon Mercury, to stop its rotation, was 700 times less than the power of the Earth on the Moon, drawing it out with its longest diameter directed to the centre of attraction and holding it there. T. L.